Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-89

Gregory N. Katnik
Process Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space Center, Florida

Technical Memorandum - 1998 - 207684 March 1998

DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-89

22 January 1998

Contributions By:

NASA, United Space Alliance,
Lockheed-Martin, Boeing North American, and Thiokol Members of the
Debris/Ice/TPS and Photographic Analysis Teams

Approved:

James G. Tatum
Chief, ET/SRB Mech/TPS Systems
NASA - KSC
Mail Code: PK-H7

Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA - KSC
Mail Code: PK-H7

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF PHOTOS

FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

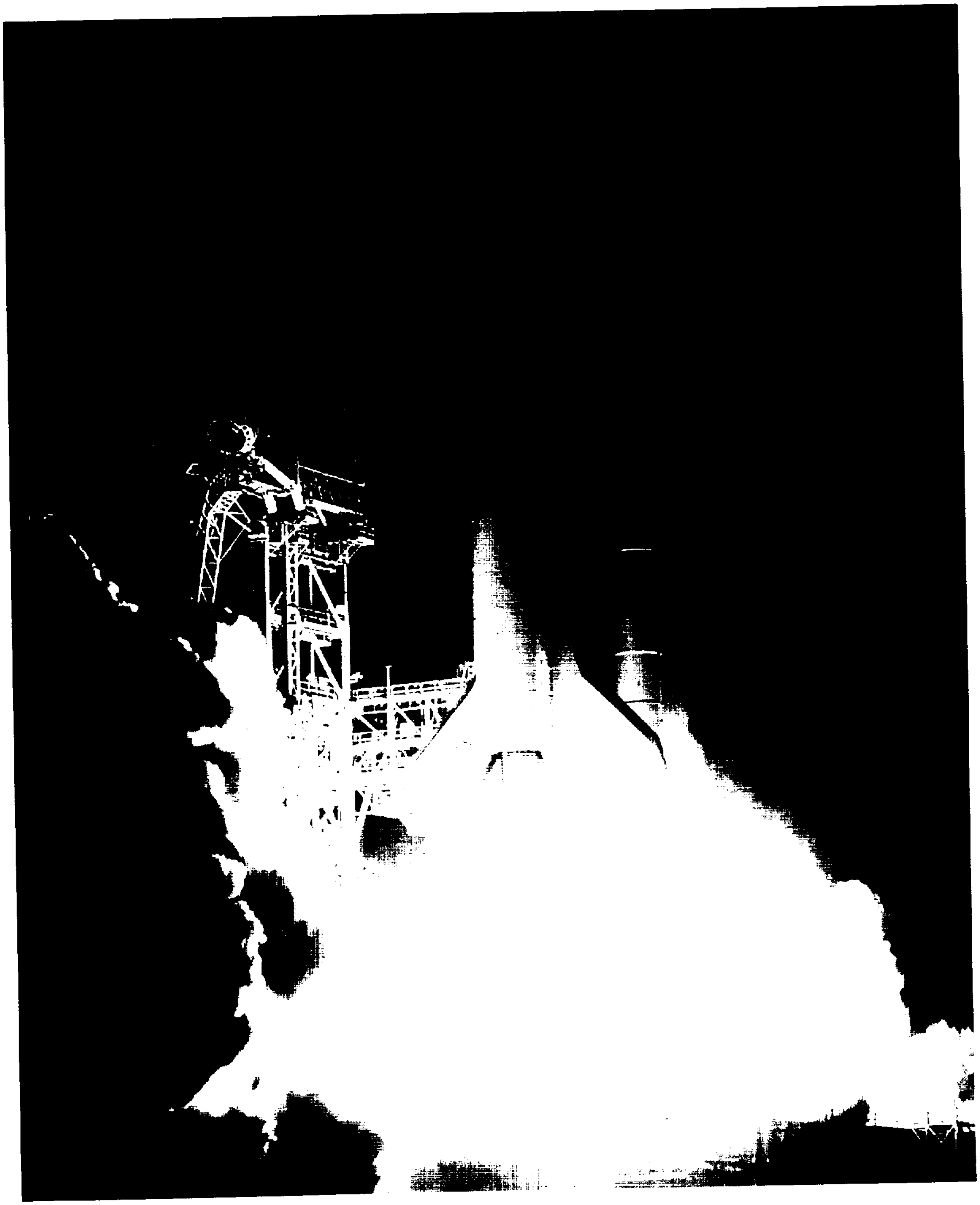


Photo 1: Launch of Shuttle Mission STS-89

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 21 January 1998. The detailed walkdown of Pad 39A and MLP-3 also included the primary flight elements OV-105 Endeavour (12th flight), ET-90 (LWT 83), and BI-093 SRB's. There were no significant vehicle or launch pad anomalies.

As a result of the STS-87 tile damage on the Orbiter and subsequent investigation of ET thrust panels, plug pull tests to verify material strength were performed on the ET-90 (STS-89) thrust panels. All of the test results were within specification. Nevertheless, the panels were then modified. The foam was machined/sanded to minimum drawing requirements above the rib tops and the rind was removed in the rib valleys to improve the stress/strain capability, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of damage to Orbiter tiles.

With the January/winter launch and a liftoff time of 9:48 p.m. local, weather conditions were expected to be favorable for the formation of acreage ice on the External Tank along with the potential for exceeding the Launch Commit Criteria.

The Final Inspection of the cryoloaded vehicle was performed on 22 January 1998 from 1700 to 1820 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Weather conditions on the day of launch were warmer than expected with ambient temperatures of 74 degrees Fahrenheit at the start of cryoloading reaching a low of 64 degrees by launch time. Consequently, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

After the 9:48 p.m. (local) launch on 22 January 1998, a debris walk down of Pad 39A was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. SRB left and right aft skirt GN2 purge lines were intact after liftoff. The purge lines were bent and the first layer of metal braid was partially melted. This condition has been noted after previous launches. Overall, damage to the launch pad was minimal.

A total of 112 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission.

No stud hang-ups were observed on any of the eight holddown posts. No ordnance debris or frangible nut pieces fell from the DCS/stud holes.

OV-105 was equipped with umbilical cameras. SRB separation from the External Tank was normal. Due to the night launch, ET separation from the SRB's was not visible. After the ET crossed the terminator into sunlight, crew hand-held images showed the BSM burn scar on the LO2 tank and the sanded +Y thrust panel could be clearly differentiated from the unsanded TPS/rind on the rest of the intertank. No divots were visible in areas other than the thrust panel with the exception of a divot in the LH2 tank-to-intertank flange closeout between the thrust panel and the LO2 feedline/PAL ramp. This divot was approximately 8 inches in diameter. Three divots could be discerned in the +Y thrust panel: two roughly aft of the EB-2 fitting and one in the -X-Z corner.

The Solid Rocket Boosters were inspected at Hangar AF after retrieval. Water impact damage, which included the nozzle extension on the left booster and the forward skirt, two segments, aft booster aft dome, systems tunnel, and ETA ring on the right booster, will not be addressed in this assessment. Both frustums were in excellent condition. No missing TPS or debonds/unbonds were detected over fasteners on the frustums. All eight BSM aero heat shield covers had locked in the fully opened position though the attach ring on the lower left cover of the right frustum had been bent by parachute riser entanglement. The forward skirts exhibited no debonds or missing TPS. Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

After the 5:35 p.m. local/eastern time landing on 31 January, 1998, a post landing inspection of OV-105 Endeavour was conducted at the Kennedy Space Center on SLF runway 15 and in the Orbiter Processing Facility bay #1. The Orbiter TPS sustained a total of 138 hits, of which 40 had a major dimension of 1-inch or larger. A comparison of these numbers to statistics from 72 previous missions of similar configuration indicates the total number of hits was slightly greater than average and the number of hits 1-inch or larger was significantly greater than average.

The Orbiter lower surface sustained 95 total hits, of which 38 had a major dimension of 1-inch or larger. Most of this damage was concentrated near the outboard edges in a line generally running from the nose landing gear to the main landing gear. These damage sites follow the same location pattern documented on STS-86 and STS-87. Although the numbers were greater than the fleet averages for the lower surface, it should be noted that the quantity, sizes, and depths of the damage sites were substantially less than that of STS-87. No lower surface tiles were scrapped due to debris impact damage.

More than usual tile damage occurred on the base heat shield. The damage sites were located just forward of SSME #2 and #3 with approximately 30 areas larger than 1-inch. Most of the sites exhibited loss of tile surface coating material, but at least nine sites had estimated depths of 0.25 inches. The damage sites appeared to be caused by vibration/acoustics rather than debris impacts.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 21 January 1998 at 1500 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC	Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
J. Lin	NASA - KSC	Shuttle Ice/Debris Systems
R. Speece	NASA - KSC	Thermal Protection Systems
B. Bowen	NASA - KSC	Infrared Scanning Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
B. Davis	NASA - KSC	Digital Imaging Systems
R. Page	NASA - KSC	SSP Integration
K. Revay	USA - SPC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SPC	ET Mechanical Systems
R. Seale	USA - SPC	ET Mechanical Systems
W. Richards	USA - SPC	ET Mechanical Systems
M. Wollam	USA - SPC	ET Mechanical Systems
G. Fales	USA - SPC	ET Mechanical Systems
T. Ford	USA - SPC	ET Mechanical Systems
J. McClymonds	BNA - DNY	Shuttle Aerodynamics
F. Foster	BNA - LSS	Systems Integration
C. Hill	BNA - LSS	Systems Integration
R. Harmon	THIO - LSS	SRM Processing
S. Otto	LMSO - LSS	ET Processing
J. Ramirez	LMSO - LSS	ET Processing
D. Maxwell	USA - Safety	

3.0 LAUNCH

STS-89 was launched at 98:023:02:48:15.017 UTC (9:48 p.m. local) on 22 January 1998.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 21 January 1998. The detailed walkdown of Pad 39A and MLP-3 also included the primary flight elements OV-105 Endeavour (12th flight), ET-90 (LWT 83), and BI-093 SRB's. There were no significant vehicle or launch pad anomalies.

As a result of the STS-87 tile damage on the Orbiter and subsequent investigation of ET thrust panels, plug pull tests to verify material strength were performed on the ET-90 (STS-89) thrust panels. All of the test results were within specification. Nevertheless, the panels were then modified. The foam was machined/sanded to minimum drawing requirements above the rib tops and the rind was removed in the rib valleys to improve the stress/strain capability, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of damage to Orbiter tiles.

With the January/winter launch and a liftoff time of 9:48 p.m. local, weather conditions were expected to be favorable for the formation of acreage ice on the External Tank along with the potential for exceeding the Launch Commit Criteria. However, weather predictions the day before launch indicated ambient temperatures warmer than normal (71 degrees Fahrenheit decreasing to 64 degrees by T-0), lower than expected relative humidity (85 percent), and fairly strong westerly winds (12-18 knots). The SURFICE computer program calculated the ET surface temperatures would range from 47 to 55 degrees F.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 22 January 1998 from 1700 to 1820 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Weather conditions on the day of launch were warmer than expected with ambient temperatures of 74 degrees Fahrenheit at the start of cryoloading reaching a low of 64 degrees by launch time. Consequently, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster covers were intact though one cover on thruster F1L was tinted green indicating a slight internal vapor leak. Ice/frost and condensate had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 64 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted condensate, but no ice or frost, on the ET acreage TPS.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 62 degrees F.

The intertank acreage exhibited no TPS anomalies, including the sanded thrust panels. Ice/frost accumulation on the base of the GUCP appeared typical.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 62 degrees F and the +Z side and 58 degrees F on the -Z side. The difference between the two sides was expected and attributed to the new "thick/thin" TPS configuration.

Less than usual amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A 10-inch long by ¼-inch wide stress relief crack had formed, as expected, on the -Y vertical strut forward facing TPS.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were limited to small patches on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch.

No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

3.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing did not increase noticeably. Even with the decrease in ambient temperature, no icing concerns were predicted. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected.

Photo 2: STS-89 Ready for Launch

OV-105 Endeavour (12th flight), ET-90 (LWT 83), and BI-093 SRB's. The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 62 degrees F.

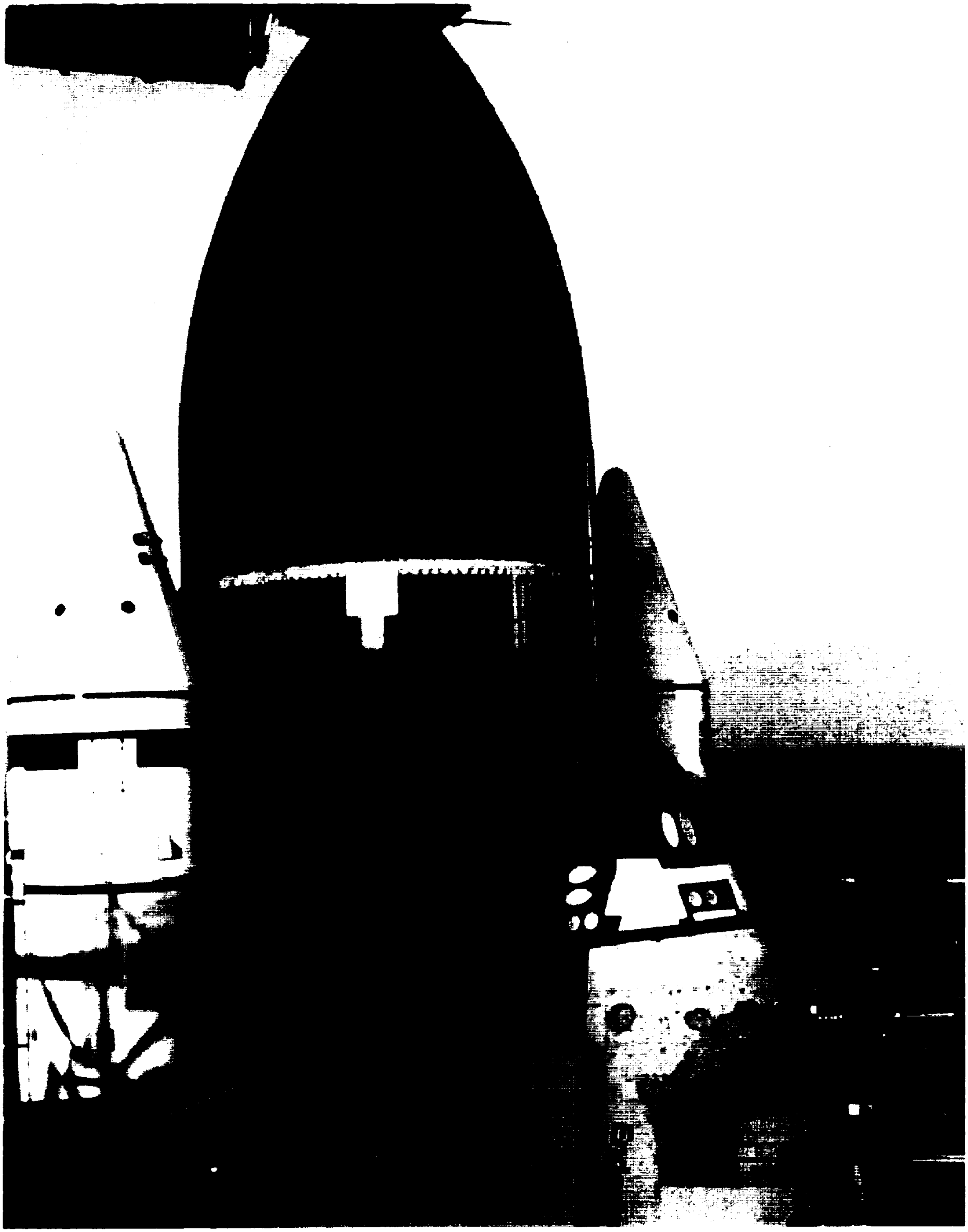


Photo 3: LO2 Tank After Cryoload

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 62 degrees F. Note configuration change to the -Y thrust panel, which had been sanded.

Photo 4: Sanded Thrust Panels

Pre-launch view of the +Y thrust panel. As a result of the STS-87 tile damage and subsequent investigation of ET thrust panels, the ET-90 panels were modified. Foam was machined/sanded to minimum drawing requirements above the rib tops and the rind was removed in the rib valleys to improve the stress/strain capability, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of Orbiter tile damage.

Photo 5: Intertank/GUCP After Cryoload

The intertank acreage exhibited no TPS anomalies, including the sanded thrust panels. Ice/frost accumulation on the base of the GUCP appeared typical. The amount of vapors emanating from the GUCP area was also typical.

Photo 6: LH2 Tank After Cryoload

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents.

Photo 7: Overall View of SSME's

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 3, Pad A FSS, RSS, and pad apron was conducted on 22 January 1998 from Launch + 1 to 3 hours. No flight hardware was found.

No stud hang-ups occurred on this launch. Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.06 g's, which is below the threshold (0.14 g's) for stud hang-ups. SRB hold down post erosion was less than usual. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. SRB left and right aft skirt GN2 purge lines were intact after liftoff. The purge lines were bent and the first layer of metal braid was partially melted. This condition has been noted after previous launches.

The Tail Service Masts (TSM's) appeared undamaged and the bonnets were closed properly. Likewise, the Orbiter Access Arm (OAA) was undamaged.

The GH2 vent line was latched in the sixth of eight teeth of the latching mechanism. The GUCP 7-inch QD surface exhibited three scuff marks from contact with the static retract lanyard. The most evident contact mark was visible at the 12 o'clock position. All observations indicated a nominal retraction and latchback though the GH2 vent line exhibited heat effects/damage from the SRB exhaust plume.

The GOX vent seals were in excellent shape with no indications of plume damage. No topcoat from the External Tank nose cone adhered to the seals.

Debris findings on the MLP were few this launch probably due to the south wind at T-0. On the FSS, grating clamps were shaken loose from several levels, a LH2 vent line gage window had separated from the gage, an electrical junction box was partially torn from a mounting post, and a 2-foot by 1-foot access panel lay on the 275-foot level deck. The pad apron was also cleaner than usual. Only an access panel was found on the west side. Several glass panes were broken in the north stadium lights.

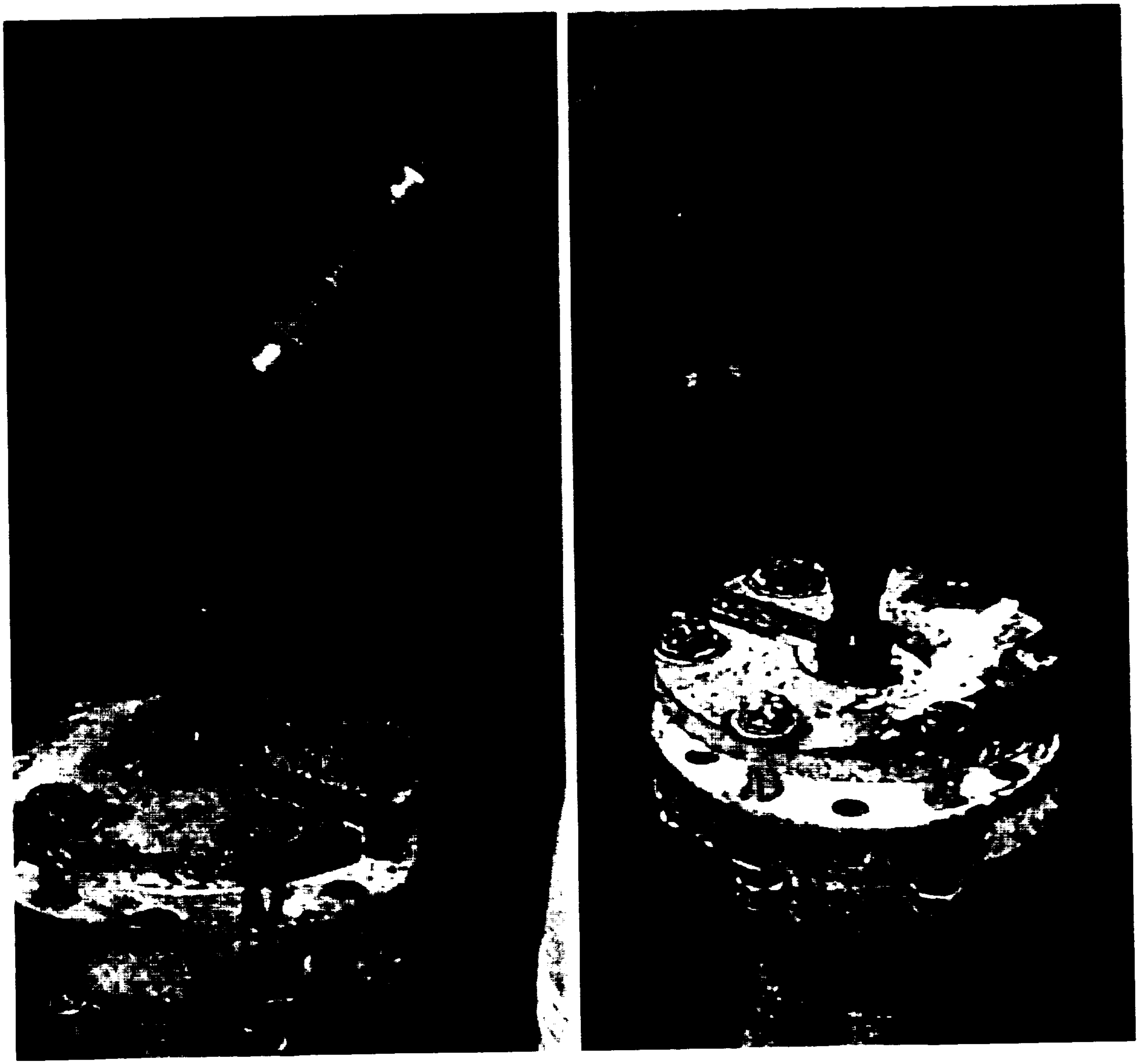


Photo 8: Left SRB Aft Skirt GN2 Purge Line

Left SRB aft skirt GN2 purge line was intact after liftoff. The purge line was bent and the first layer of metal braid was partially melted. This condition has been noted after previous launches.

Photo 9: Right SRB Aft Skirt GN2 Purge Line

Right SRB aft skirt GN2 purge line was intact after liftoff

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 85 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-nine videos, were reviewed starting on launch day.

SSME ignition appeared normal. Noticeable amounts of free burning hydrogen were blown under the body flap by the southerly winds. Three debris-induced streaks occurred in the SSME #1 exhaust plume at 48:13.836, 48:16.155, and 48:16.886 UTC (E-2, -3, -19, -20; OTV-051, -054, -063, -070, TV-7).

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals (OTV-009). Two pieces of ice fell from the LO2 feedline upper bellows. No contact with lower surface tiles was detected (OTV-061).

No anomalies were detected on the External Tank nose cone. No ice was present (OTV-013, -060, -062).

Four light spots near the -Y+Z end and two place on the +Y+Z end of the body flap may be small areas of tile surface coating material lost during engine ignition (E-76, -77).

Surface coating material was lost during ignition from an area on the base heat shield that spanned 3 or 4 tiles between SSME #2 and the body flap. Coating material was also lost from one place each on both RCS stinger aft surfaces, three places on the base heat shield around SSME #3, and four places on the base heat shield adjacent to and outboard of SSME #2 (E-17, -18; OTV-049).

An unusual vapor trail, or streak, was visible in the vicinity of the ET aft dome or SRB right aft booster at 48:15.724 UTC as condensate vapors were drawn aft by engine aspiration. The vapor trail was most likely a phenomenon of condensate vaporizing and air flow patterns at the time of liftoff (E-31, -52).

There were no stud hang-ups. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. The north HDP blast covers closed normally. A small debris object, believed to be a piece of duct tape, fell outboard of HDP #2 and into the exhaust hole (E-8). At liftoff, the RSS cable near HDP #8 pulled two small pieces of foam loose from the aft ring. A wedge-shape piece of foam, estimated to be 8-inches long by 5-inches wide by 2-inches thick, appeared out of the SRB exhaust hole and moved along the MLP deck shortly after liftoff (E-14).

The GN2 purge lines separated cleanly from both SRB aft skirts at liftoff. SRB exhaust plume impingement later caused very slight side to side motions in both flex lines. The purge lines were visible for about two seconds after T-0 before being obscured from view by the SRB exhaust smoke (E-8, -13).

GUCP disconnect from the ET was normal (E-33).

Ice particles from the LO2 feedline upper bellows fell outboard of the EO fitting (E-5).

A large, backlit debris object, possibly a piece of SRB throat plug, was ejected from the SSME flame trench after the vehicle had left the field of view (OTV-070).

The two white particles below the left elevon at 48:18.053 UTC are believed to be pieces of ice falling from the LH2 ET/ORB umbilical (E-63).

Contrails from both wing tips were visible during and after the roll maneuver - an expected occurrence given the ambient weather conditions (OTV-041, TV-4A).

Numerous light-colored particles falling along side the SRB exhaust plumes starting at T+16 seconds MET are believed to be pieces of SRB aft skirt instafoam (E-57).

Film item E-207 provided a good, clear view of body flap motion, which was similar to previous flights. The motion is also visible in film item E-220.

At least 7 particles, believed to be pieces of aft skirt instafoam, fell aft along side the SRB exhaust plume from T+66 to T+77 seconds MET (TV-4A).

SRB separation appeared normal. The quantity and size of slag particles appeared to be similar to that observed on previous night launches (E-212; TV-4A).

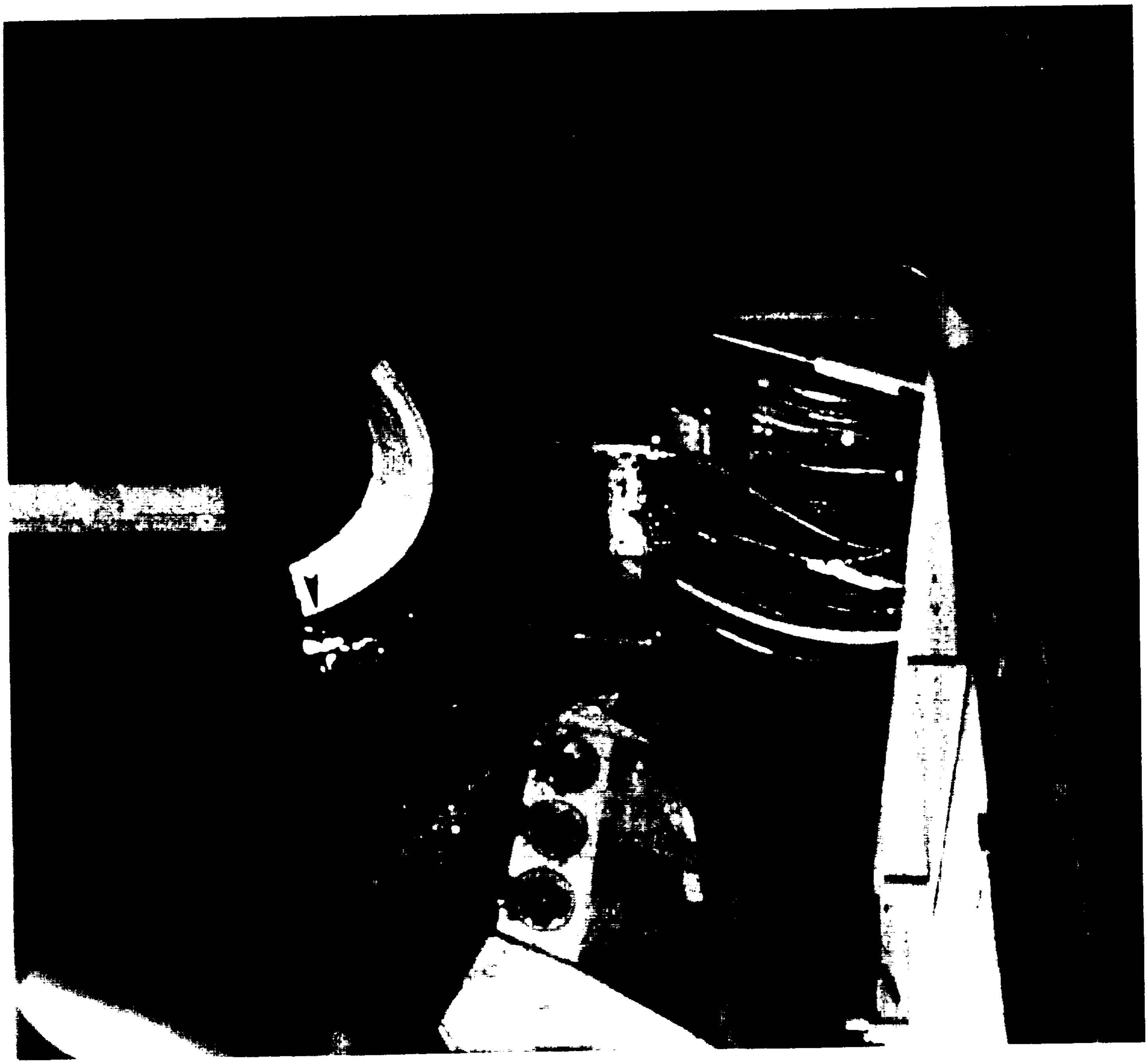


Photo 10: Base Heat Shield Tile Damage

Surface coating material was lost during ignition from an area on the base heat shield that spanned 3 or 4 tiles between SSME #2 and the body flap

Photo 11: Vapor Trail at Liftoff

An unusual vapor trail, or streak, was visible in the vicinity of the ET aft dome or SRB right aft booster at 48:15.724 UTC as condensate vapors were drawn aft by engine aspiration. The vapor trail was most likely a phenomenon of condensate vaporizing and air flow patterns at the time of liftoff.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-105 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The 35mm images from the LO2 umbilical were dark due to the night launch. Consequently, ET separation from the Orbiter was not visible in either the 16mm or 35mm films. Hand-held photography by the flight crew, which consisted of thirty-seven still 35mm images and a 3-minute video, showed the ET substantially in shadow. In addition, the ET was comparatively small in the frame due to the 4-5 kilometer distance from the Orbiter (photography of the ET was later than usual in the time line while the flight crew waited to cross the terminator and sunlight to illuminate the ET).

Frames 015 and 020 show the -Y-Z quadrant. Although the thrust panel is mostly in shadow and no divots can be discerned, the two bright spots in the intertank have been identified as reflections from the flight door and the EB-1 fitting.

Frames 009, 013, 023, 024, and 028 are the best views of the +Y+Z quadrant. The BSM burn scar on the LO2 tank and the sanded +Y thrust panel can be clearly differentiated from the unsanded TPS/rind on the rest of the intertank. No divots were visible in areas other than the thrust panel with the exception of frame 028, which shows a divot in the LH2 tank-to-intertank flange closeout between the thrust panel and the LO2 feedline/PAL ramp. This divot was approximately 8 inches in diameter.

Frame 023 shows three divots in the +Y thrust panel: two roughly aft of the EB-2 fitting and one in the -X-Z corner.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 23 films and videos, which included nine 35mm large format films, two 16mm films, and twelve videos, were reviewed.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. The main landing gear contacted the runway almost simultaneously slightly east of the centerline. Touchdown of the nose landing gear was smooth. The Orbiter continued rolling east of the centerline until the drag chute was deployed before being steered to the centerline.

Drag chute operation appeared nominal. Rollout and wheel stop were uneventful.

TPS damage on the lower surface of both right and left glove area was visible in some of the films. Larger than usual tile damage was also visible on the base heat shield between SSME #1 and #2.

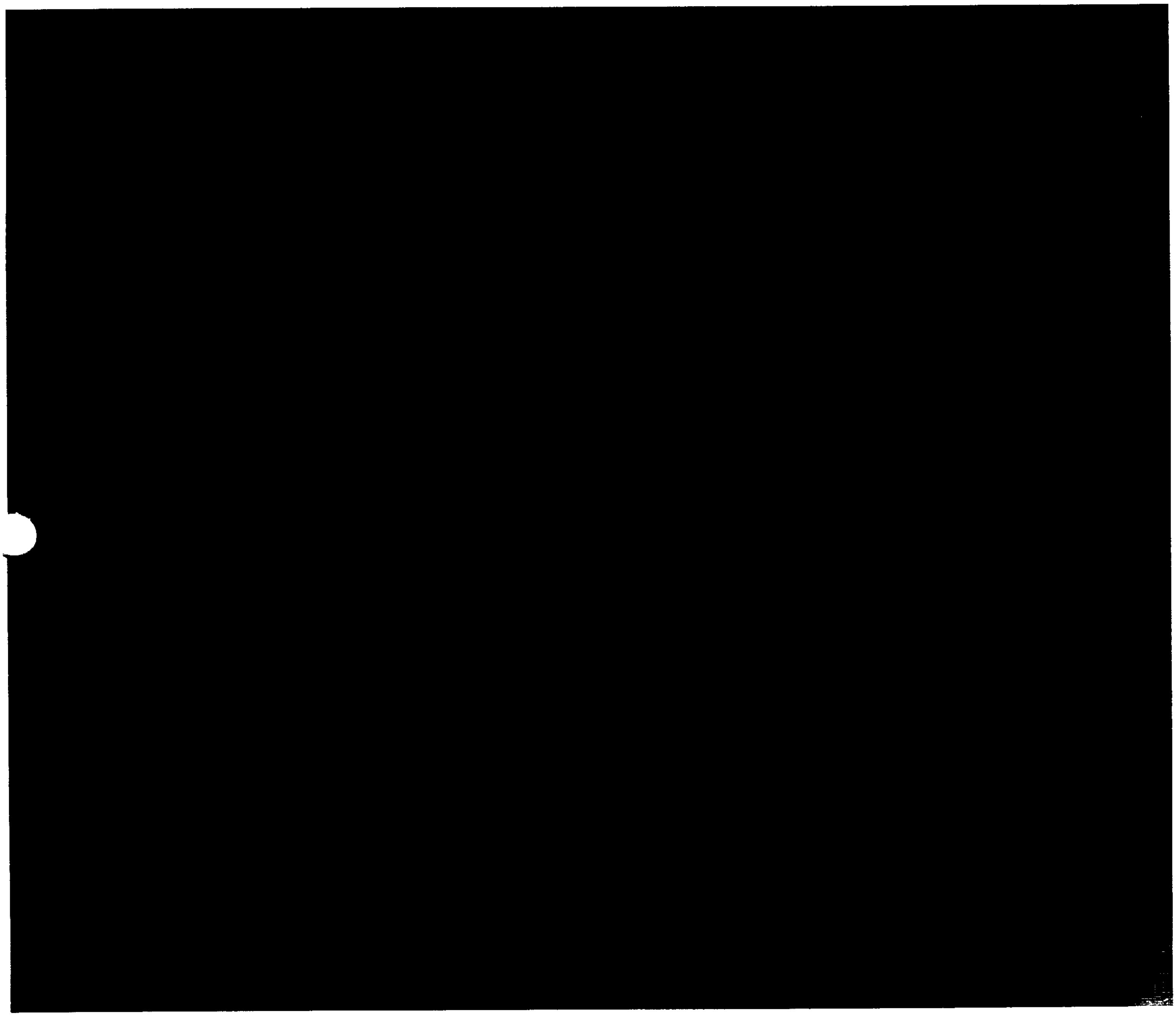


Photo 12: SRB Separation From External Tank

SRB separation from the External Tank was normal. TPS charring and erosion from the aft surfaces of the LH2 ET/ORB umbilical cable tray and the -Y vertical strut was typical. Small "popcorn" type divots on the NCFI-covered ET aft dome were also typical.

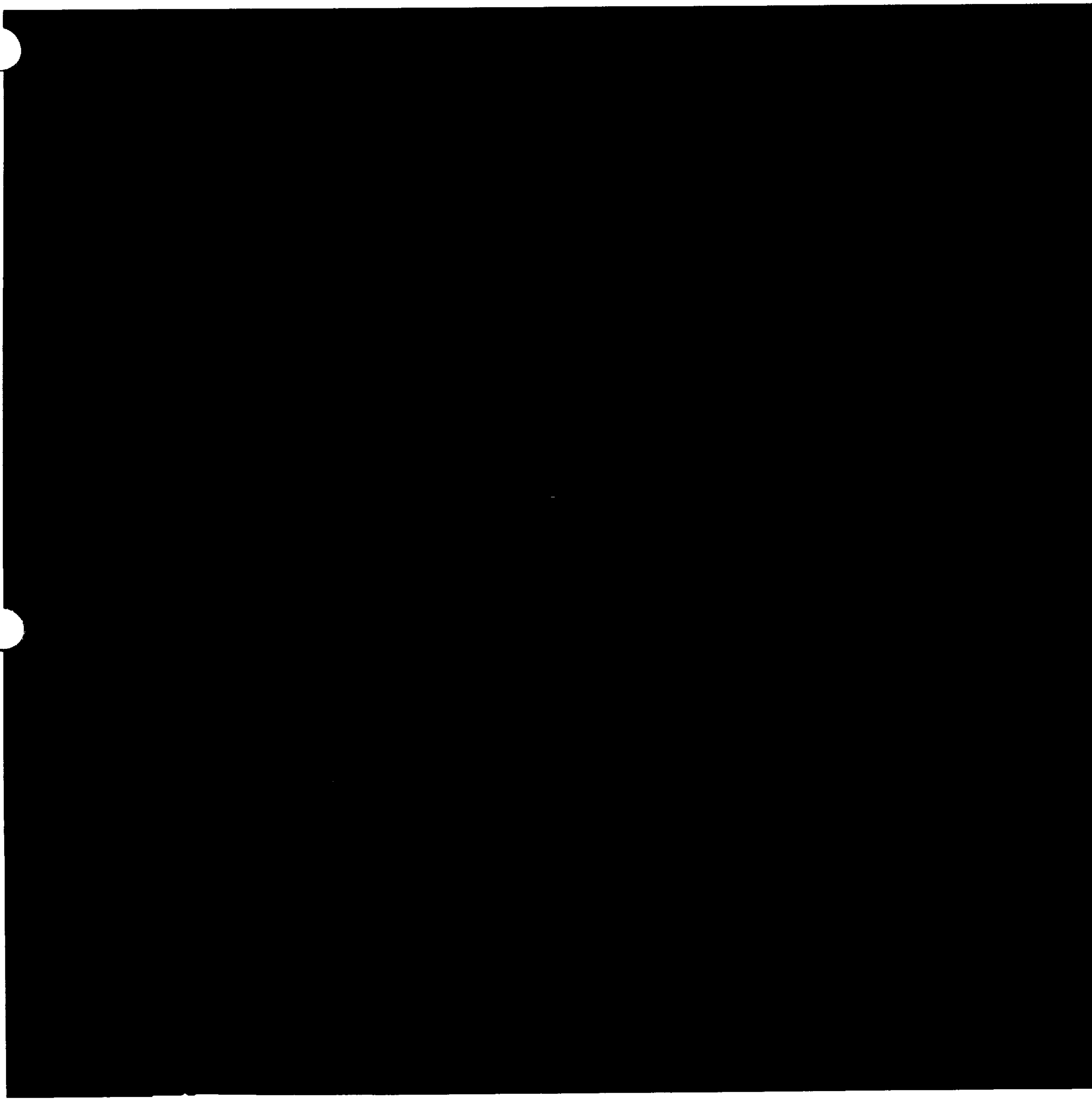


Photo 13: ET After Separation From Orbiter

The BSM burn scar on the LO2 tank and the sanded +Y thrust panel can be clearly differentiated from the unsanded TPS/rind on the rest of the intertank. No divots were visible in areas other than the thrust panel with the exception of a divot in the LH2 tank-to-intertank flange closeout between the thrust panel and the LO2 feedline/PAL ramp (arrow). This divot is approximately 8 inches in diameter.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-093 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 27 January 1998. Water impact damage, which included the nozzle extension on the left booster and the forward skirt, two segments, aft booster aft dome, systems tunnel, and ETA ring on the right booster, was not addressed in this assessment.

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners. Virtually none of the Hypalon paint had blistered in the expected areas. However, a BTA patch on the left frustum XB-318 ring frame exhibited extensive blistering/ missing Hypalon paint over the full circumference. The exposed BTA was not sooted. All eight BSM aero heat shield covers had locked in the fully opened position though the attach ring on the lower left cover of the right frustum had been bent by parachute riser entanglement. Note: a configuration change had been made to the frustums. The PR-1422 sealant/cap closeouts had been eliminated from the majority of the fastener heads prior to the application of ablator. There were no debonds, unbonds, or missing TPS associated with this change.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. All frustum severance ring pins and retainer clips were intact.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. The leading edge of the left SRB forward field joint closeout near the 180 degree axis exhibited small areas of missing material and a streak of green paint. A more detailed examination revealed this damage had been caused by recovery operations contacting the flight hardware in heavy seas. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally. However, the HDP #5 DCS plunger was not fully seated though there was no visible obstruction. The HDP #1 DCS plunger was completely obstructed by a frangible nut half. There were no stud hang-ups on this launch.

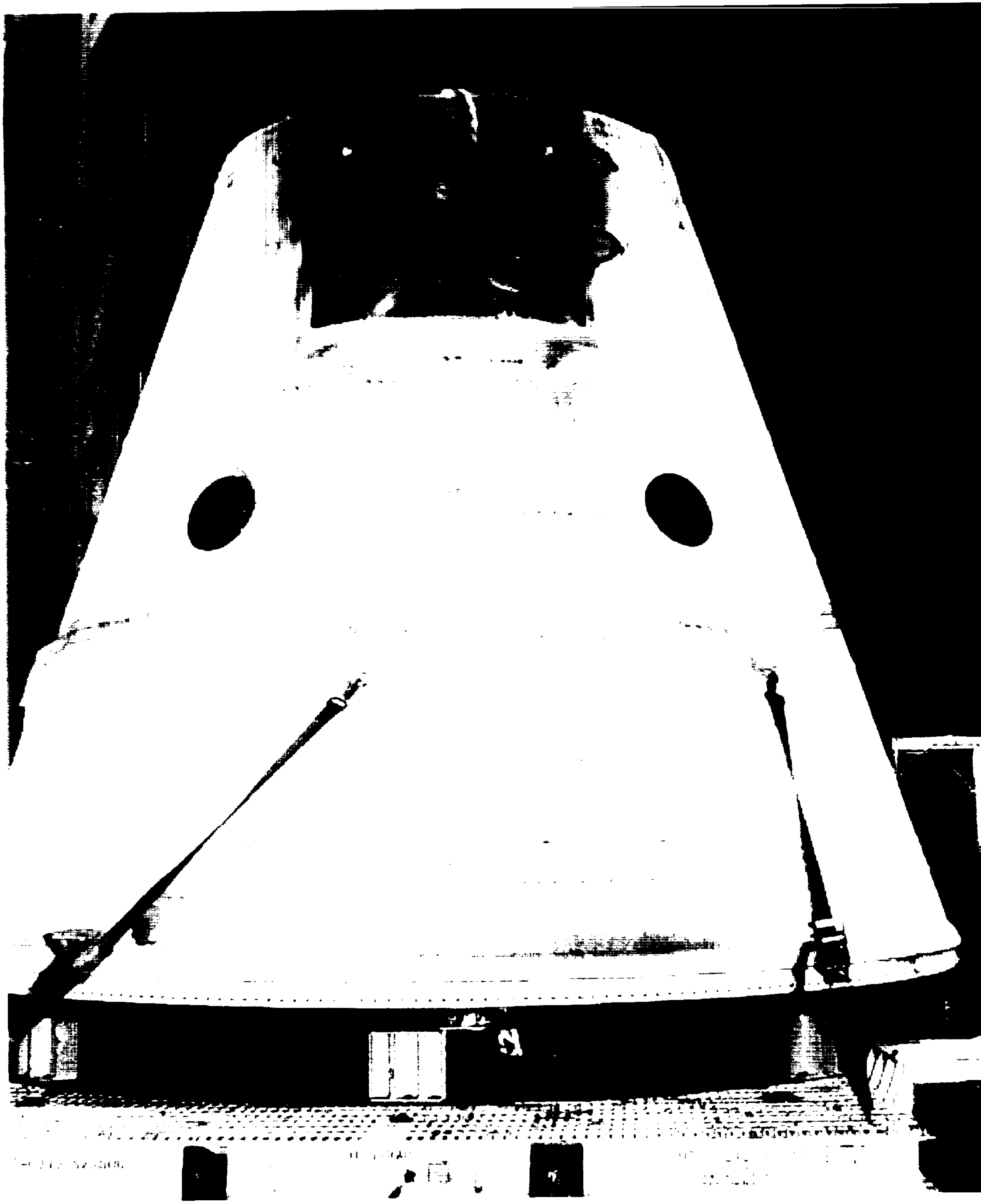


Photo 14: Frustum Post Flight Condition

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners. All eight BSM aero heat shield covers had locked in the fully opened position though the attach ring on the lower left cover of the right frustum had been bent by parachute riser entanglement. Note: a configuration change had been made to the frustums. The PR-1422 sealant/cap closeouts had been eliminated from the majority of the fastener heads prior to the application of ablator. There were no debonds, unbonds, or missing TPS associated with this change.

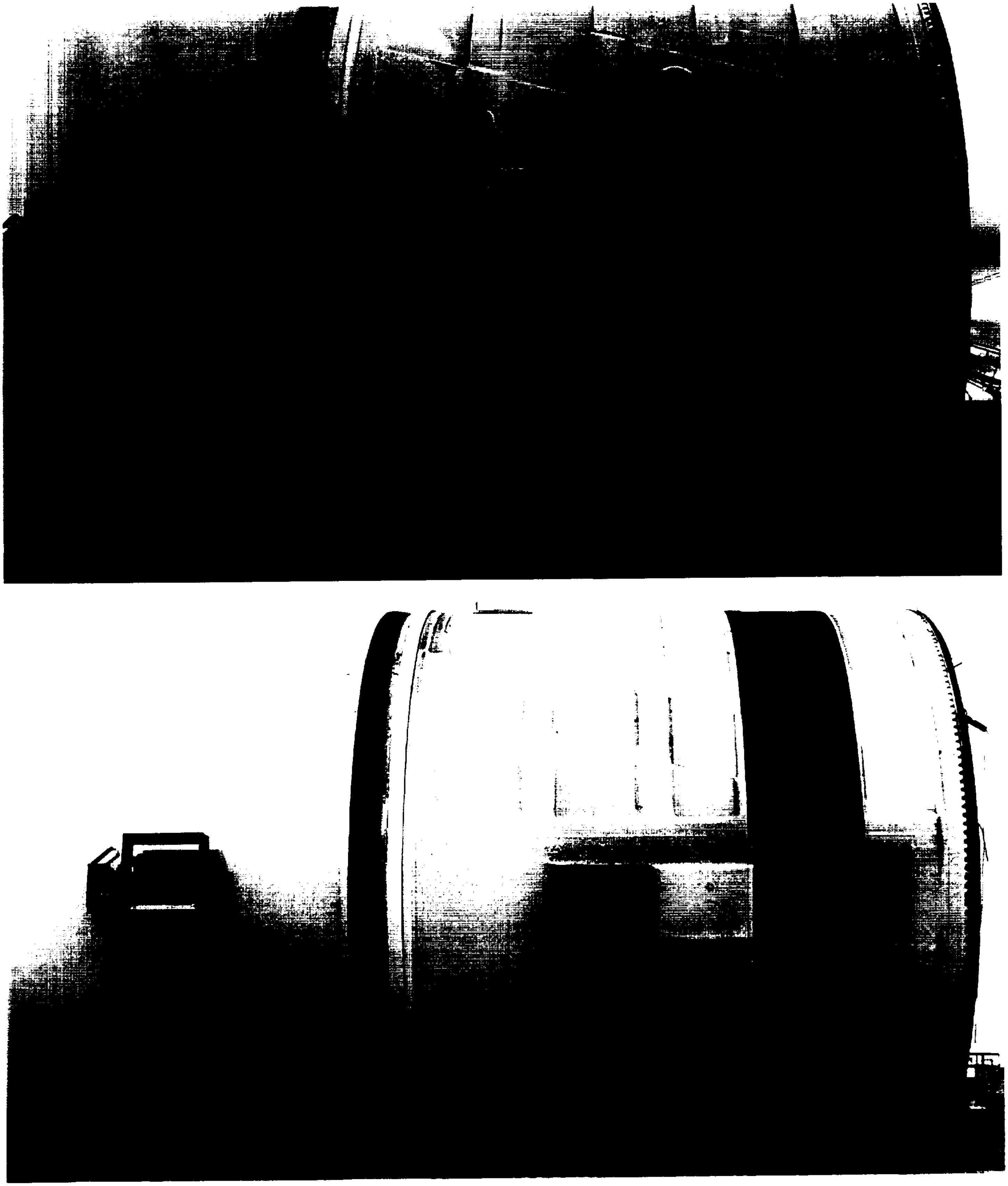
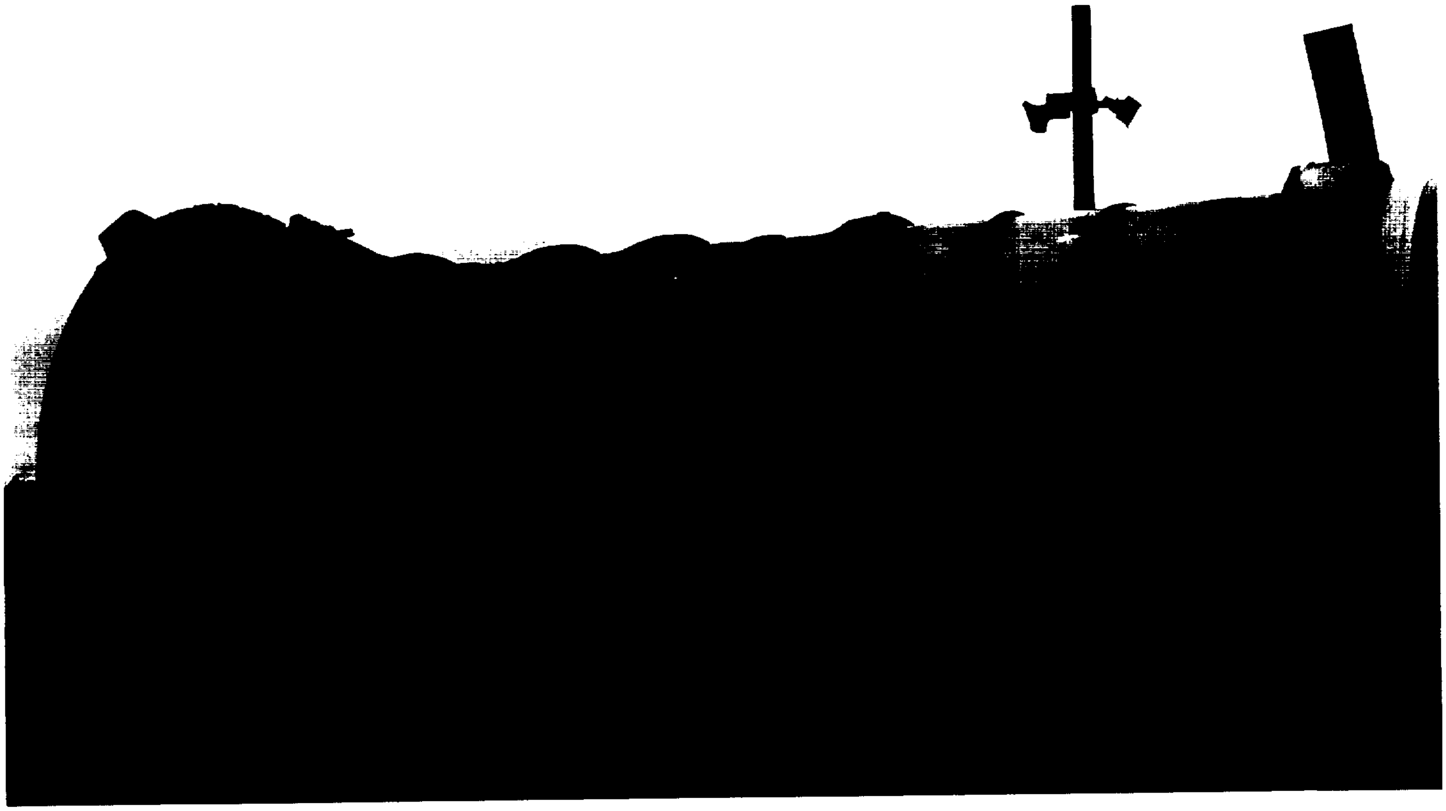


Photo 15: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. All frustum severance ring pins and retainer clips were intact. Note water impact damage to the right forward skirt (top photo).



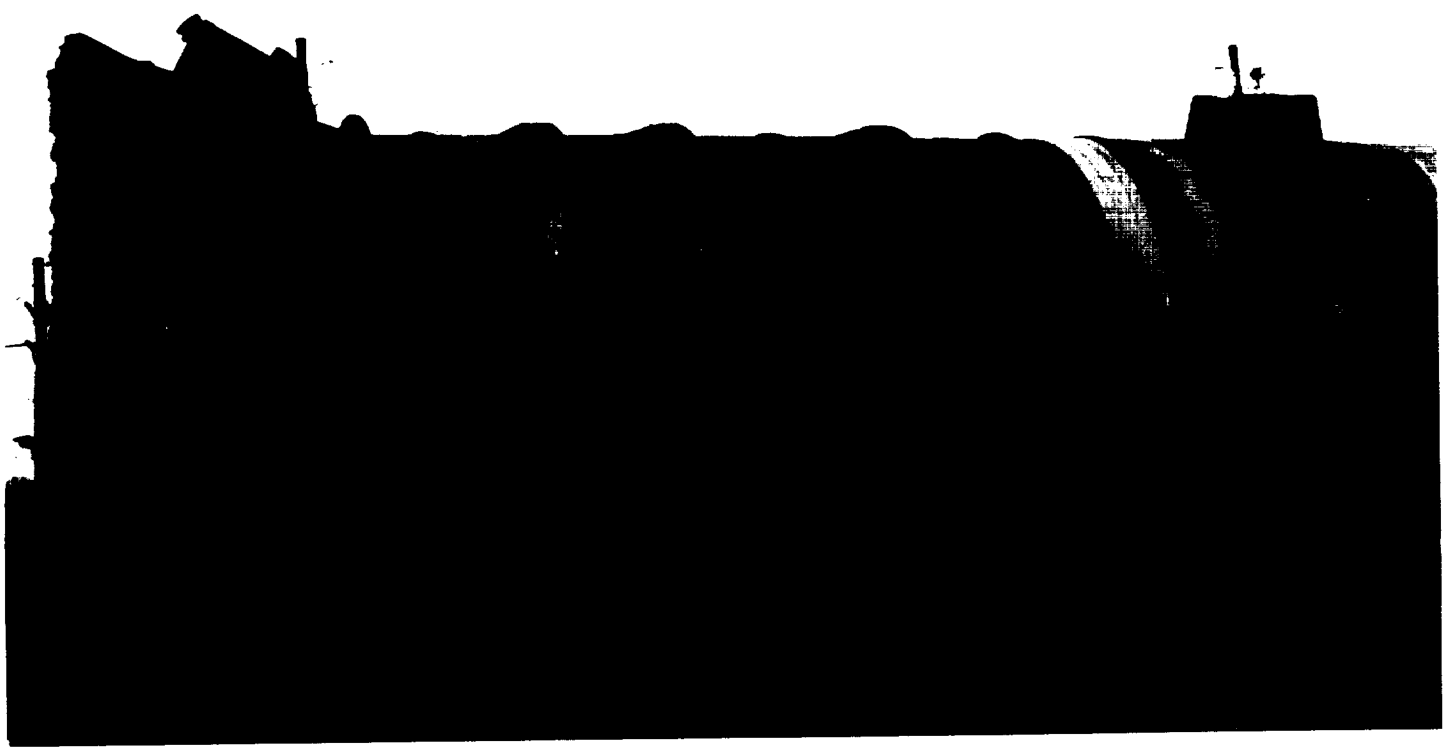


Photo 16: Aft Booster/Aft Skirt Post Flight Condition

Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition. Note water impact damage to the right SRB ETA ring cover (top photo).

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 5:35 p.m. local/eastern time landing on 31 January, 1998, a post landing inspection of OV-105 Endeavour was conducted at the Kennedy Space Center on SLF runway 15 and in the Orbiter Processing Facility bay #1. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 138 hits, of which 40 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 72 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30, 42, 86, and 87, which had damage from known debris sources), indicates the total number of hits was slightly greater than average and the number of hits 1-inch or larger was significantly greater than average (reference Figures 1-4).

The following table breaks down the STS-89 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	38	95
Upper surface	0	1
Window Area	0	21
Right side	1	7
Left side	1	3
Right OMS Pod	0	5
Left OMS Pod	0	6
TOTALS	40	138

The Orbiter lower surface sustained 95 total hits, of which 38 had a major dimension of 1-inch or larger. Most of this damage was concentrated near the outboard edges in a line generally running from the nose landing gear to the main landing gear. These damage sites follow the same location pattern documented on STS-86 and STS-87. Although the numbers were greater than the fleet averages for the lower surface, it should be noted that the quantity, sizes, and depths of the damage sites were substantially less than that of STS-87:

	STS-86	STS-87	STS-89	Fleet Average
Lower surface total hits	100	244	95	83
Lower surface hits > 1-inch	27	109	38	13
Longest damage site	7 in.	15 in.	2.8 in.	N/A
Deepest damage site	0.4 in.	1.5 in.	0.2 in.	N/A

No lower surface tiles were scrapped due to debris impact damage. The largest lower surface tile damage site was located on the right inboard elevon. The site measured 4-inches long by 1-inch wide by 0.2-inches deep and was most likely caused by an impact from ET/ORB umbilical ice. The deepest lower surface tile damage site (0.5 inches) was located aft of the ET/ORB umbilicals on the body flap and was probably also associated with an ice impact.

Tile damage sites around and immediately aft of the LH2 and LO2 ET/ORB umbilicals were less than usual. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The tires, which exhibited no ply undercutting, were reported to be in excellent condition for a landing on the KSC concrete runway.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. The EO-2 and EO-3 fitting retainer springs were in nominal configuration. No clips were missing from the "salad bowls". Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

More than usual tile damage occurred on the base heat shield. The damage sites were located just forward of SSME #2 and #3 with approximately 30 areas larger than 1-inch. Most of the sites exhibited loss of tile surface coating material, but at least nine sites had estimated depths of 0.25 inches. The damage sites appeared to be caused by vibration/acoustics rather than debris impacts.

The SSME #2 and #3 Dome Mounted Heat Shield (DMHS) closeout blankets were in good condition. However, the blanket panels on SSME #1 at the 5:00 and 7:00 o'clock positions were torn/frayed.

No ice adhered to the payload bay door. No unusual tile damage occurred on the leading edges of the vertical stabilizer and OMS pods. Most of the tile damage on the OMS pods was attributed to old surface coating material flaking off. Three protruding tile gap fillers were noted.

Hazing and streaking of forward-facing Orbiter windows was less than usual. The 21 small damage sites on the window perimeter tiles was less than usual in quantity and size. The larger damage sites were attributed to old material falling out and were not included in this assessment. The underlying SIP was visible in two damage sites around window #3 and one site around window #2 where the perimeter tile meets the glass, but there was no residue or streak nearby on the glass indicating a debris impact.

The post landing walkdown of Runway 15 was performed immediately after landing. No debris concerns were identified. All drag chute hardware was recovered and appeared to have functioned normally. The two pyrotechnic devices on the reefing line cutters had been expended.

In summary, the total number of Orbiter TPS debris hits was slightly above the fleet average and the number of hits 1-inch or larger was significantly greater than the fleet average when compared to previous missions (reference Figures 5-6).

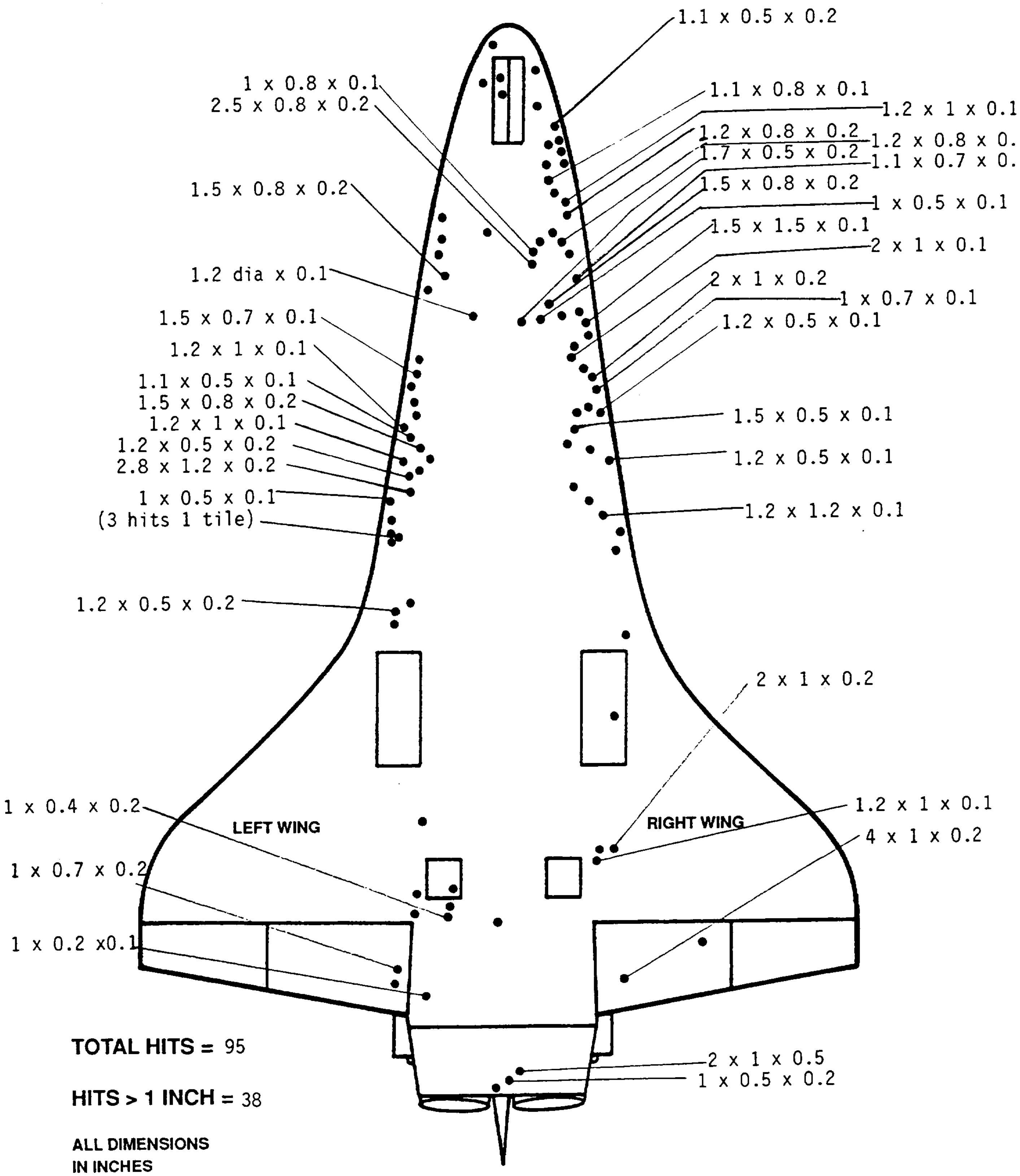


Figure 1: Orbiter Lower Surface Debris Damage Map

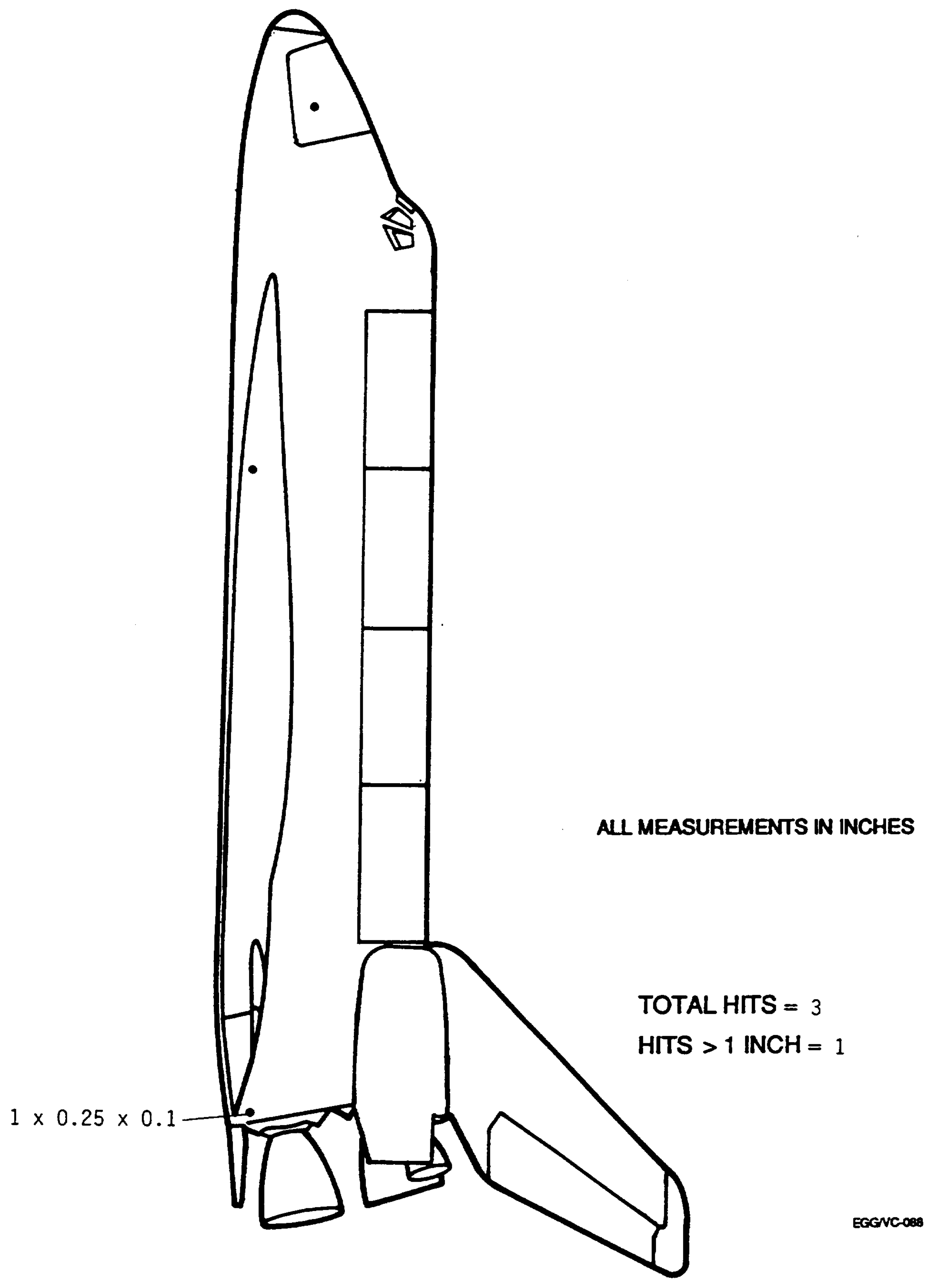


Figure 2: Orbiter Left Side Debris Damage Map

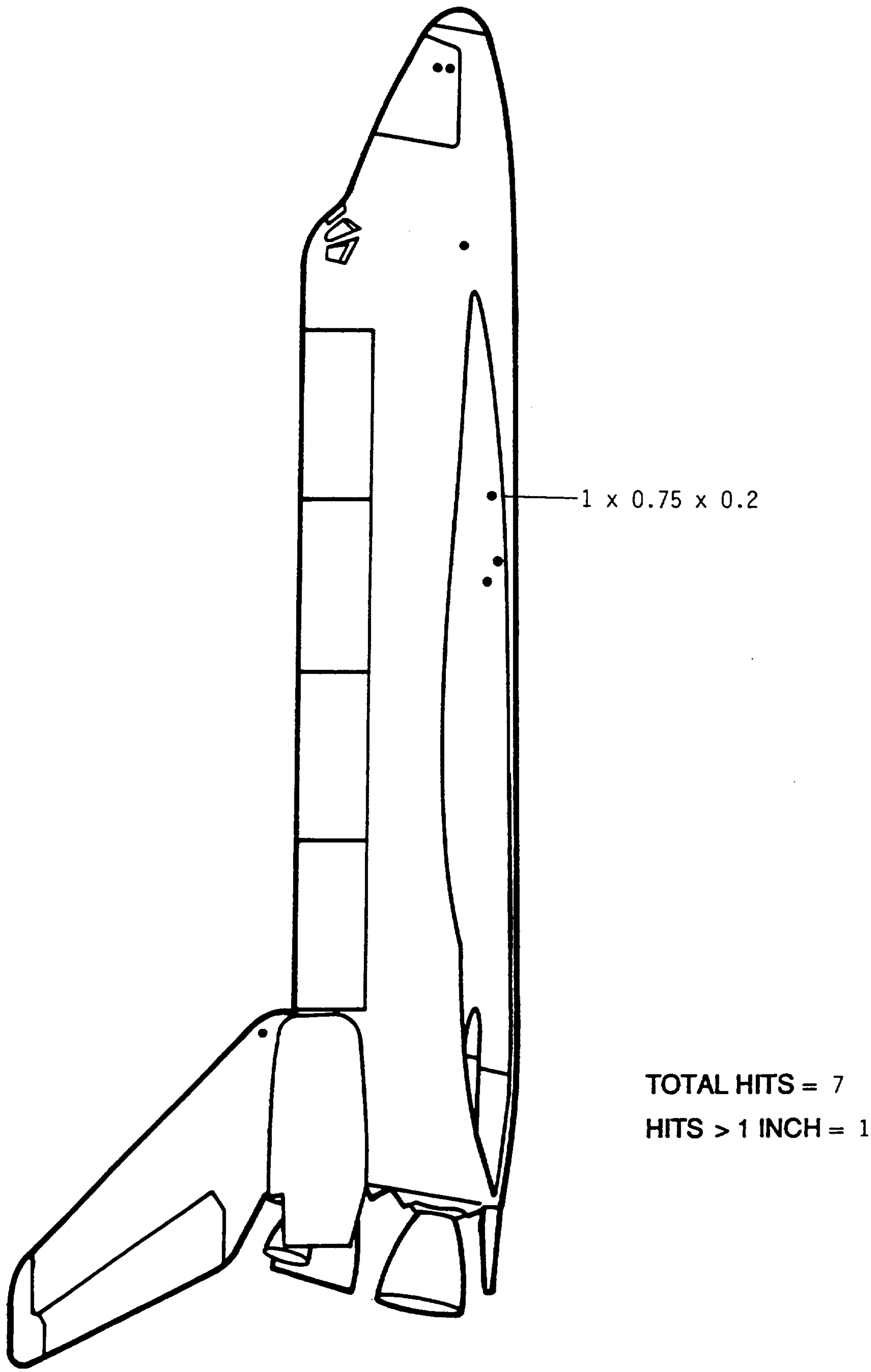


Figure 3: Orbiter Right Side Debris Damage Map

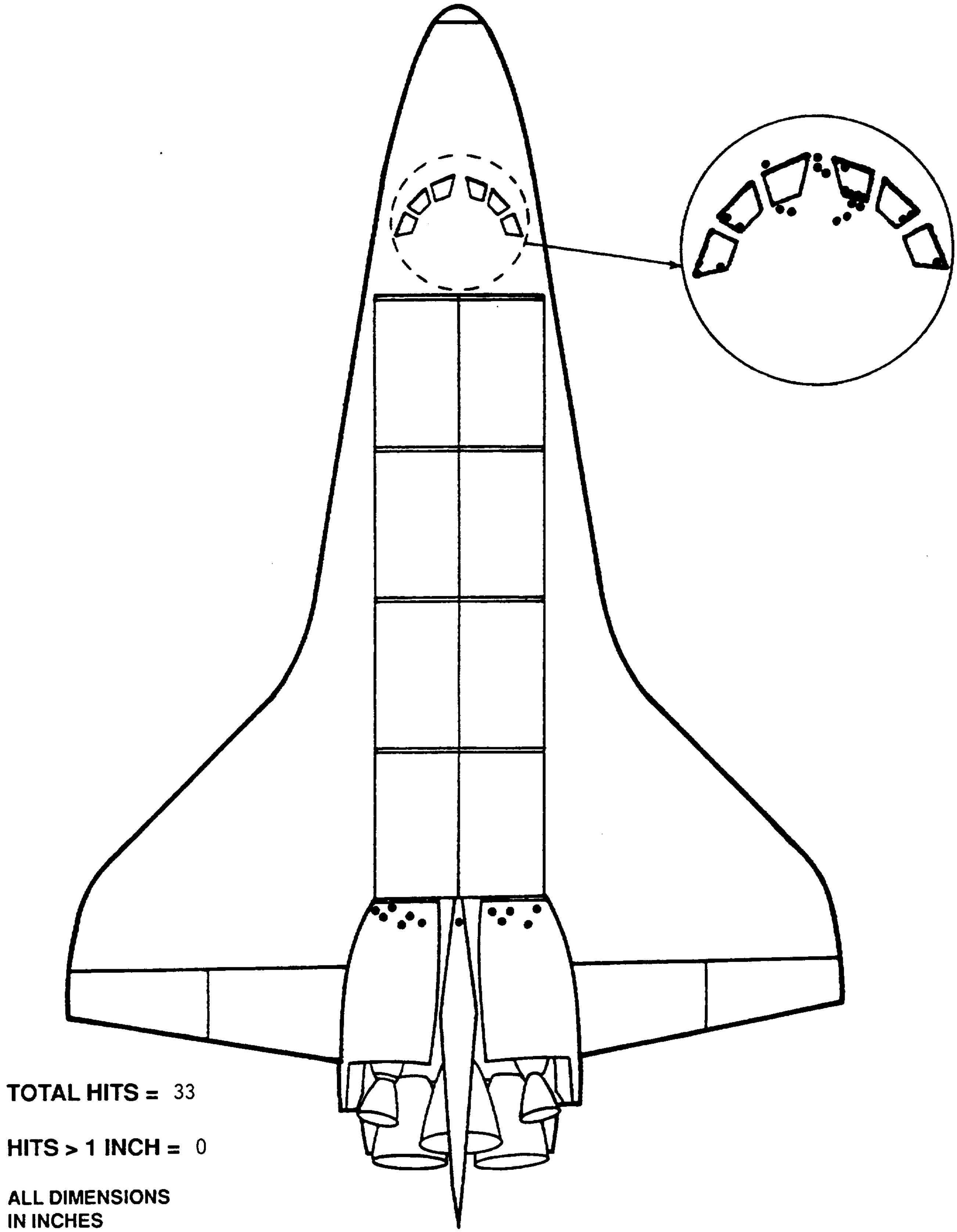


Figure 4: Orbiter Upper Surface Debris Damage Map

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156

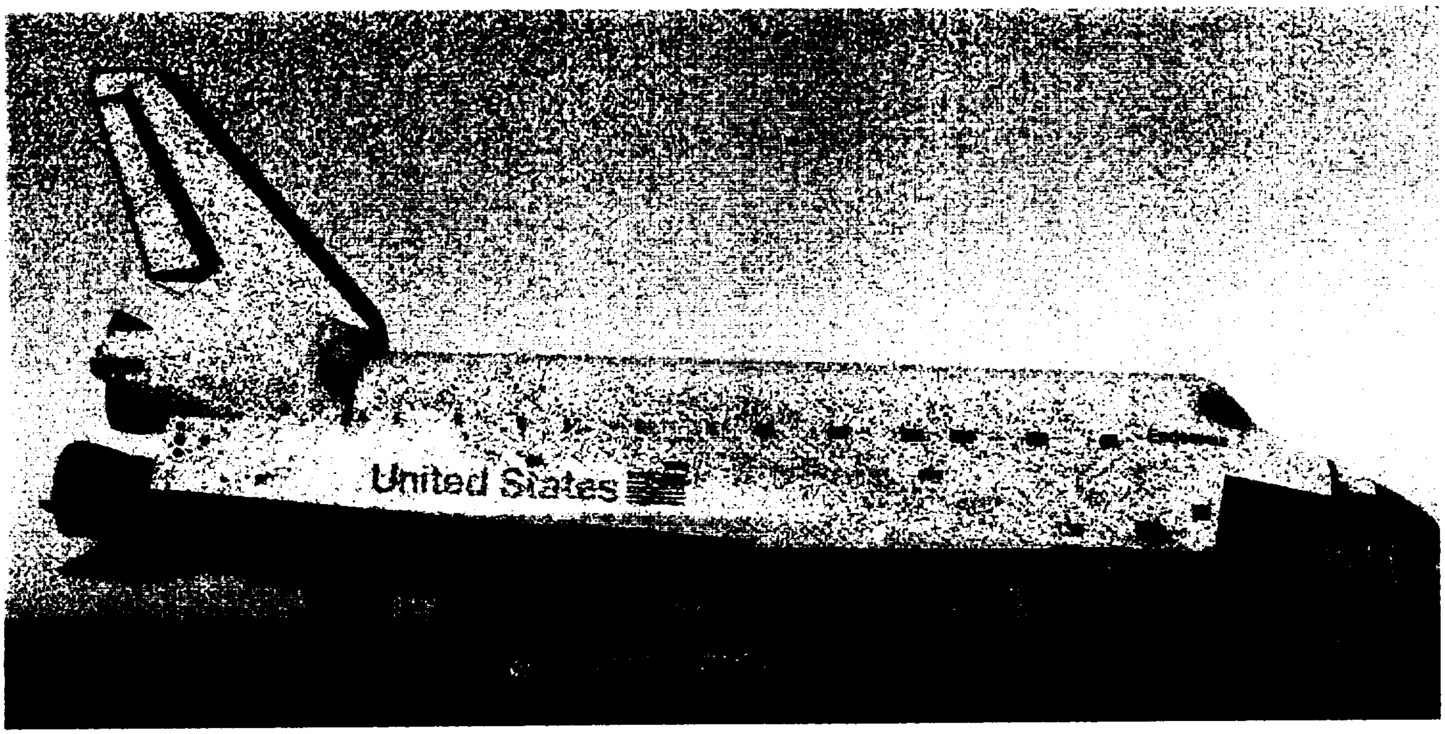
	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
AVERAGE	13.3	83.2	19.6	124.3
SIGMA	7.1	43.9	9.5	51.9
STS-89	38	95	40	138

MISSIONS STS-23,24,25,26,26R,27R,30R,42, 86, AND 87 ARE NOT INCLUDED IN THIS ANALYSIS
SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 5: Orbiter Post Flight Debris Damage Summary

SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES					
	LOWER SURFACE		ENTIRE SURFACE		CAUSE OR SOURCE
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS	
STS-23	Not Available	Not Available	46	152	ET Intertank TPS
STS-24	Not Available	Not Available	63	140	ET Intertank TPS
STS-25	109	231	144	315	ET Intertank TPS
STS-26	179	482	226	553	ET Intertank TPS
STS-26R	47	342	55	411	SRB DFI Cork Closeouts
STS-27R	272	644	298	707	SRB Nosecap Ablator
STS-30R	52	134	56	151	LH MLG Tire Rubber Pieces
STS-42	38	159	44	209	ET Intertank TPS
STS-86	27	100	31	129	ET Thrust Panel TPS
STS-87	109	244	132	308	ET Thrust Panel TPS

Figure 6: Orbiter Debris Exclusion Damage Summary



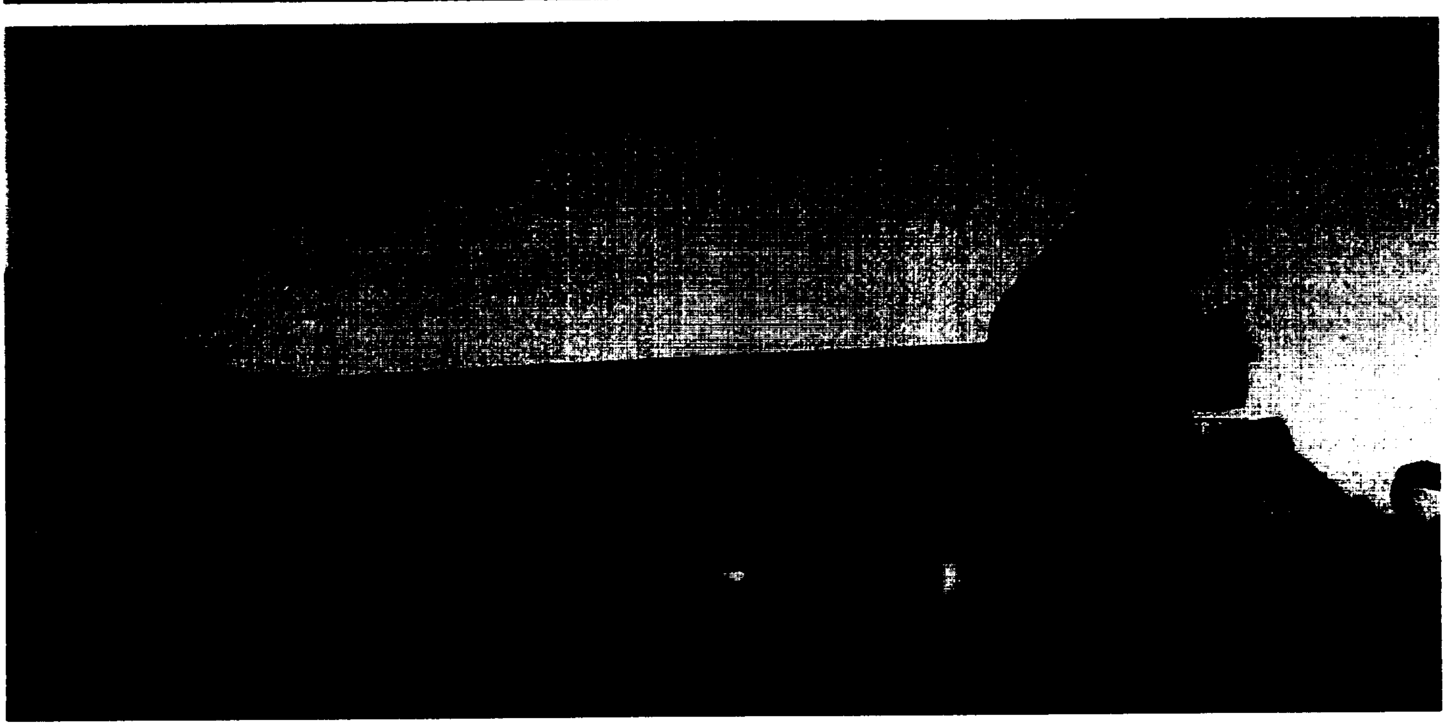


Photo 17: Overall View of Orbiter Sides

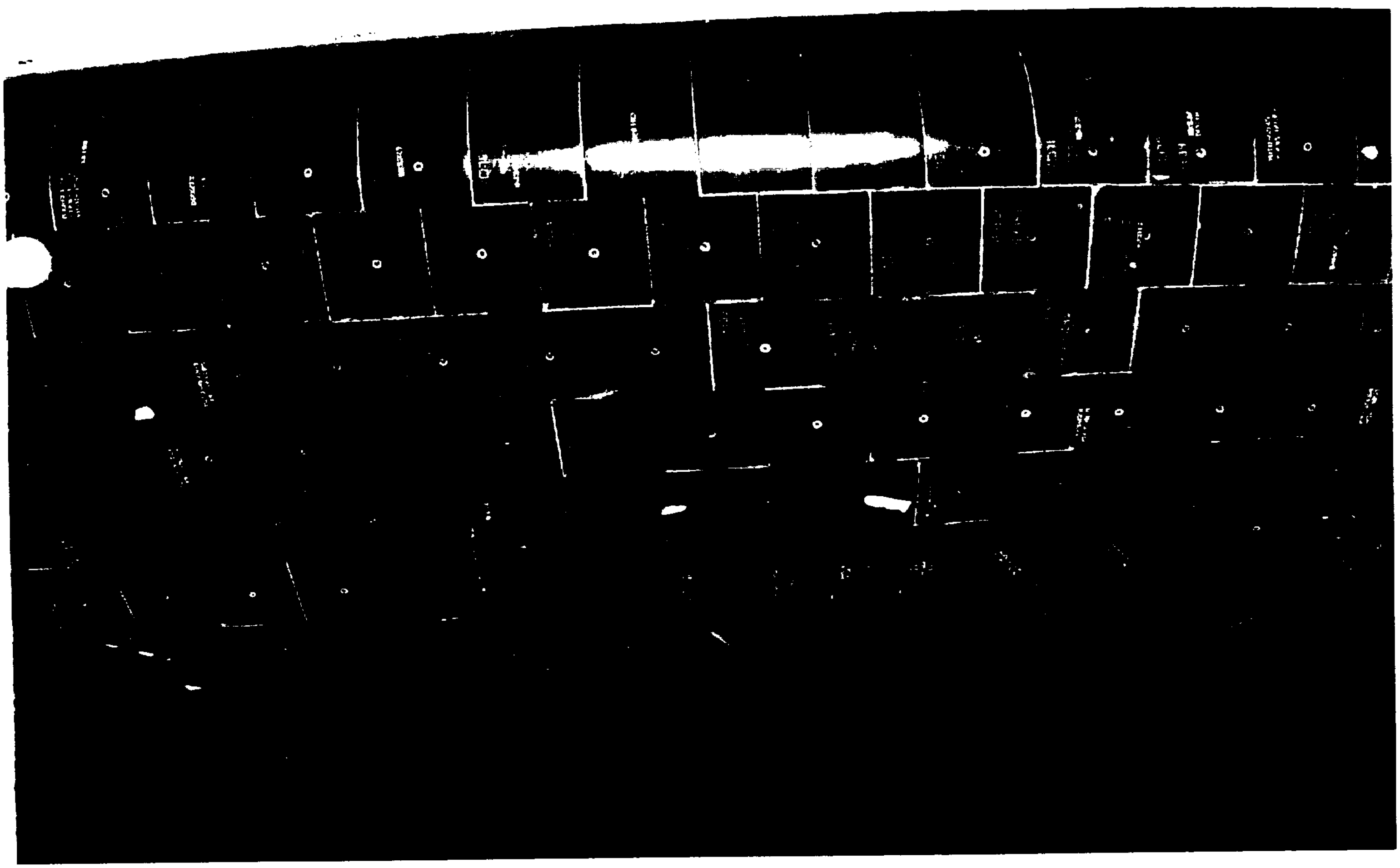


Photo 18: Lower Surface Tile Damage

The Orbiter lower surface sustained 95 total hits, of which 38 had a major dimension of 1-inch or larger. Most of this damage was concentrated near the outboard edges in a line generally running from the nose landing gear to the main landing gear. These damage sites follow the same location pattern documented on STS-86 and STS-87. Although the numbers were greater than the fleet averages for the lower surface, it should be noted that the quantity, sizes, and depths of the damage sites were substantially less than that of STS-87

Photo 19: SSME DMHS Closeout Blanket

The SSME #2 and #3 Dome Mounted Heat Shield (DMHS) closeout blankets were in good condition. However, the blanket panels on SSME #1 at the 5:00 and 7:00 o'clock positions were torn/frayed.

Photo 20: Base Heat Shield Tile Damage

More than usual tile damage occurred on the base heat shield. The damage sites were located just forward of SSME #2 and #3 with approximately 30 areas larger than 1-inch. Most of the sites exhibited loss of tile surface coating material, but at least nine sites had estimated depths of 0.25 inches. The damage sites appeared to be caused by vibration/acoustics rather than debris impacts.

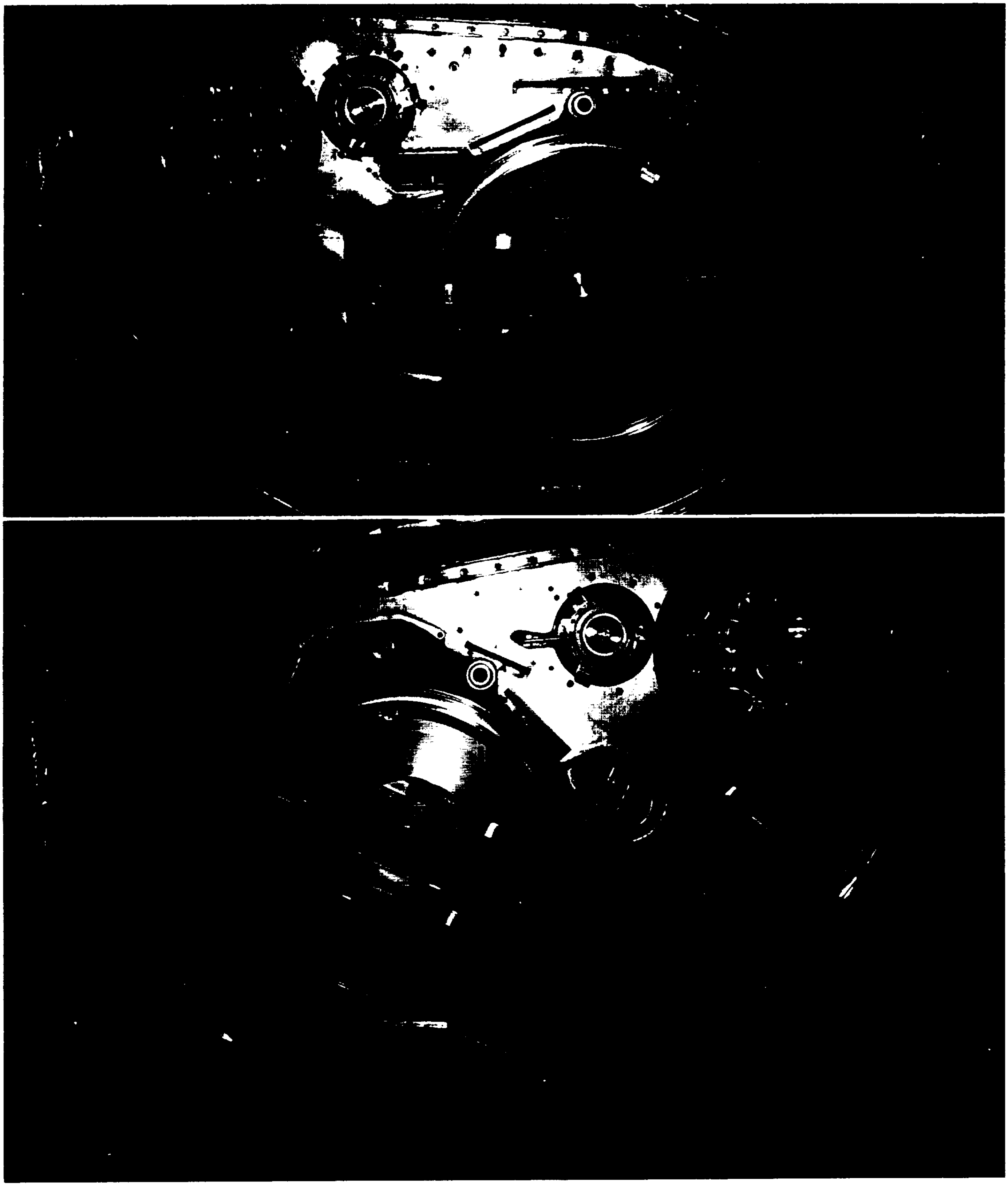
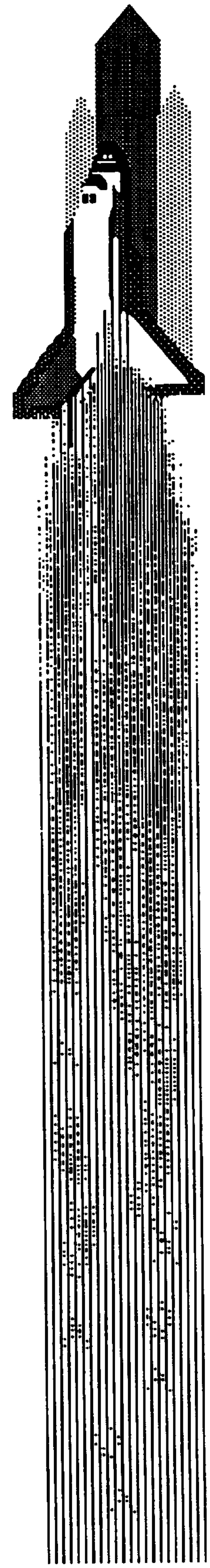


Photo 21: LO2 and LH2 ET/ORB Umbilicals

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Science Branch
Image Science and Analysis Group



STS-89 Summary of Significant Events

March 6, 1998

Space Shuttle
Image Science and Analysis Group
STS-89 Summary of Significant Events

Project Work Order - SN5CA

Approved By

Lockheed Martin

Jon Disler 3/6/98

Jon Disler, Project Analyst
Image Science and Analysis Group

NASA

Michael T Gaunce

Mike Gaunce, Lead
Image Science and Analysis Group
Space Science Branch

Clyde A Sapp 3-6-98

C. A. Sapp, Project Manager
Image Analysis Projects

Jess G. Carnes

Jess G. Carnes, Operations Manager
Basic and Applied Research Department

Prepared By

Lockheed Martin Engineering and Sciences Company
for
Space Science Branch
Earth Sciences and Solar System Exploration Division
Space and Life Sciences Directorate

Table of Contents

Table and Figures

1. STS-89 (OV-105): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-89 launch of Endeavor (OV-105) from pad A occurred on January 23, 1998 at approximately 02:48:15.22 Coordinated Universal Time (UTC), as seen on camera OTV049. Solid Rocket Booster (SRB) separation occurred at approximately 02:50:18.327 UTC, as seen on camera E223.

On launch day, 24 of the 24 expected videos were received and screened. Following launch day, 20 films were screened. Twenty-one additional films were received for contingency support and anomaly resolution, but were not screened.

Photography of the left SRB and the LSRB/ET aft attach and the external tank aft dome was acquired using umbilical well camera films during SRB separation. Handheld still photography of the ET was acquired following separation. Also, handheld video of the ET was acquired. Numerous pieces of debris (probably ice) were visible throughout the video sequence.

1.1.2 On-Orbit

No on-orbit tasks were requested.

1.1.3 Landing

Endeavor made an early morning landing on runway 15 at the KSC Shuttle Landing Facility on January 31, 1998. Twelve videos and ten films were received and screened following the landing.

Normal APU venting was seen during the landing approach through roll-out and wheel stop (EL17IR, EL18IR).

The drag chute deployment appeared normal.

1.1.4 Post Landing

The following items were seen on the post landing walk-around inspection video: Orbiter lower surface tile damage extending aft from the nose gear to both main landing gears; tile damage on the Orbiter base heat shield and both the left and right RCS stingers; and normal tile erosion on the upper surface of the body flap. Tile damage around the Orbiter windows appeared to be less than normal. No significant tile damage was seen on the OMS pods. The LH2 and LO2 umbilicals appeared to be in good condition. The landing gear tires appeared to be in good condition.

1.2 TIMING ACTIVITIES

The time codes from videos and films were used to identify specific events during the screening process.

The landing and drag chute event times are provided in Table 1.2.

Event Description	Time (UTC)	Camera
Landing Gear Doors Opened	031:22:34:49.386	EL9
Left Main Gear Touchdown	031:22:35:09.202	EL7
Right Main Gear Touchdown	031:22:35:09.222	EL7
Drag Chute Initiation	031:22:35:12.726	EL7
Pilot Chute at Full Inflation	031:22:35:13.564	EL7
Bag Release	031:22:35:14.306	EL4
Drag Chute Inflation in Reefed Configuration	031:22:35:15.449	EL4
Drag Chute Inflation in Disreefed Configuration	031:22:35:18.394	EL10
Nose Gear Touchdown	031:22:35:20.261	EL12
Drag Chute Release	031:22:35:53.196	EL9
Wheel Stop	031:22:36:20.070	EL2

Table 1.2 Landing Events Timing

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition through liftoff (umbilical ice debris, RCS paper, SRB flame duct debris, and water baffle debris). No damage to the vehicle was noted. No follow-up action was requested. Several pieces of SRB flame trough debris were seen traveling northward away from the vehicle at liftoff on camera E52 (02:48:15.8 UTC).

2.2 DEBRIS DURING ASCENT

Multiple pieces of light-colored debris were seen falling aft of the vehicle during ascent (E52, E207, E212, E222, E223, E224). Some of the debris seen near the SRB exhaust plume were in groups of three to twenty or more pieces. Some of the debris pieces were probably SRB aft skirt instafoam. Multiple pieces of light-colored debris, probably RCS paper and ET/Orbiter umbilical ice, were seen falling aft of the vehicle before, during, and after the roll maneuver. Some of the RCS paper debris were first seen over the wings and near the vertical stabilizer. Other debris seen falling aft along the body flap were probably ice from the ET/Orbiter umbilicals. A light-colored piece of debris first seen between the left SRB and the bodyflap was possibly LH2 umbilical purge barrier material (02:48:28.879 UTC, E52).

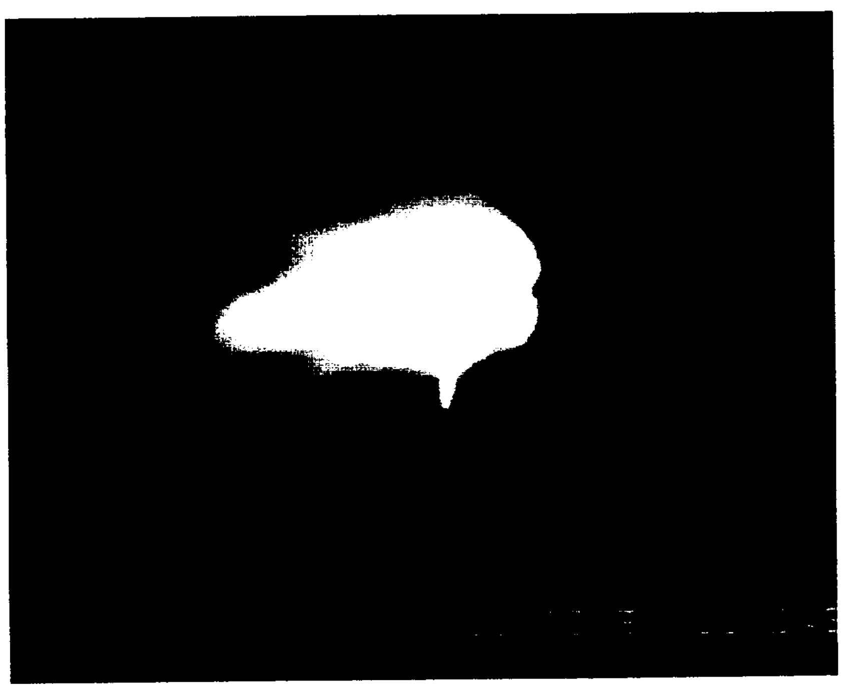


Figure 2.2 (A) Debris Seen Near SRB Exhaust Plume

Several pieces of debris were noted near the SRB exhaust plume. Tables 2.2 (A) and 2.2 (B) are timelines of representative debris sightings from film and video.

STS-89 Debris Summary from Video

Launch Phase	MET (mm:ss)	Debris	Camera
Pre-Launch	T-00:03.12	1	OTV 054
Pre-Launch	T-00:02.02	Multiple	OTV 054
Pre-Launch	T-00:01.52	1	KTV 4A
Pre-Launch	T-00:00.72	1	OTV 041
Launch	00:01.08	1	OTV 051
Launch	00:01.48	Multiple	OTV 049
Launch	00:01.68	2	KTV 5
Launch	00:02.18	1	OTV 061
Ascent	00:29.08	Multiple	ET 207
Ascent	00:36.68	1	ET 207
Ascent	00:47.18	1	ET 207
Ascent	00:51.28	1	KTV 4A
Ascent	01:01.18	1	KTV 4A
Ascent	01:04.88	2	KTV 4A
Ascent	01:06.48	1	KTV 4A
Ascent	01:09.08	1	KTV 4A
Ascent	01:09.08	2	KTV 21A
Ascent	01:10.18	2	KTV 4A
Ascent	01:10.28	1	KTV 21A
Ascent	01:10.68	1	KTV 4A
Ascent	01:11.18	1	KTV 4A
Ascent	01:14.68	1	KTV 5
Ascent	01:17.48	1	KTV 21A
Ascent	01:17.48	3	KTV 4A
Ascent	01:19.08	1	KTV 4A
Ascent	01:57.28	1	ET 207
Ascent	01:59.48	Multiple	KTV 13
Ascent	01:59.68	1	ET 207
Ascent	01:59.98	1	ET 207
Ascent	02:01.48	1	KTV 5
Ascent	02:02.98	Multiple	KTV13
Ascent	02:02.98	1	KTV13
Ascent	02:14.68	1	KTV 4A

Table 2.2 (A) Timeline of Debris Sightings (Video)

STS-89 Debris Summary from Film

Launch Phase	MET (mm:ss)	Debris	Camera
Launch	00:00.65	Multiple	E52
Ascent	00:13.47	Multiple	E224
Ascent	00:13.66	1	E52
Ascent	00:15.48	1	E224
Ascent	00:15.87	Multiple	E52
Ascent	00:17.35	3	E223
Ascent	00:18.30	Multiple	E52
Ascent	00:20.59	1	E223
Ascent	00:25.11	Multiple	E222
Ascent	00:26.01	1	E52
Ascent	00:27.76	Multiple	E223
Ascent	00:31.45	Multiple	E224
Ascent	00:32.77	1	E223
Ascent	00:51.05	1	E223
Ascent	00:55.82	1	E223
Ascent	00:56.49	1	E223
Ascent	01:01.17	1	E223
Ascent	01:04.72	Multiple	E223
Ascent	01:06.62	3	E223
Ascent	01:10.61	2	E223
Ascent	02:03.11	3	E223

Table 2.2 (B) Timeline of Debris Sightings (Film)

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

A small area of possible base heat shield erosion was noted outboard of SSME #3 during SSME ignition (E17).

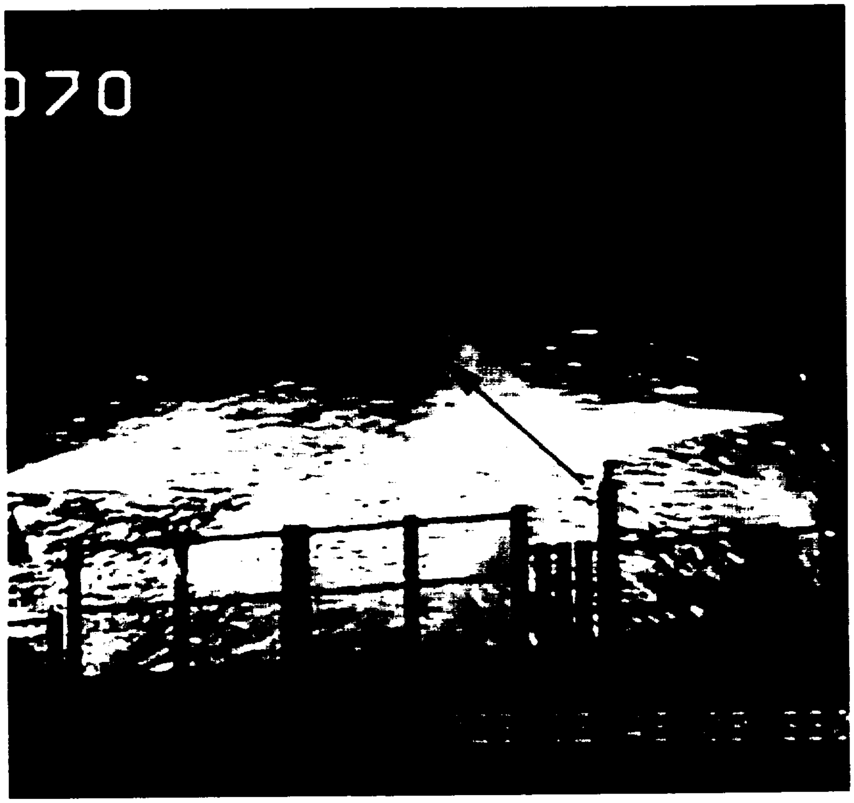


Figure 2.3 (A) Orange Vapor During SSME Ignition

Orange vapor, probably free burning hydrogen, was seen above the SSME #1 rim and near the body flap during SSME ignition at 02:48:09.3 UTC (E2, E36, E52). Orange vapor has been seen on previous missions.

Figure 2.3 (B) Flash in SSME #1 Exhaust Plume

An orange-colored flash, possibly induced by RCS paper debris, was seen in the SSME#1 exhaust plume prior to liftoff at 02:48:13.836 UTC (E2, E20, E76).

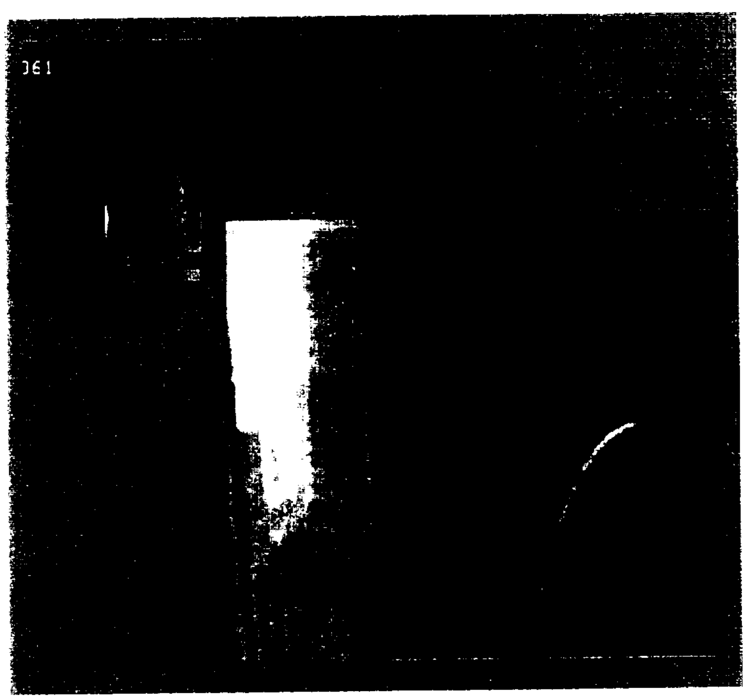


Figure 2.3 (C) Intertank Vent

Vapor was seen coming from the +Z intertank vent prior to lift-off.

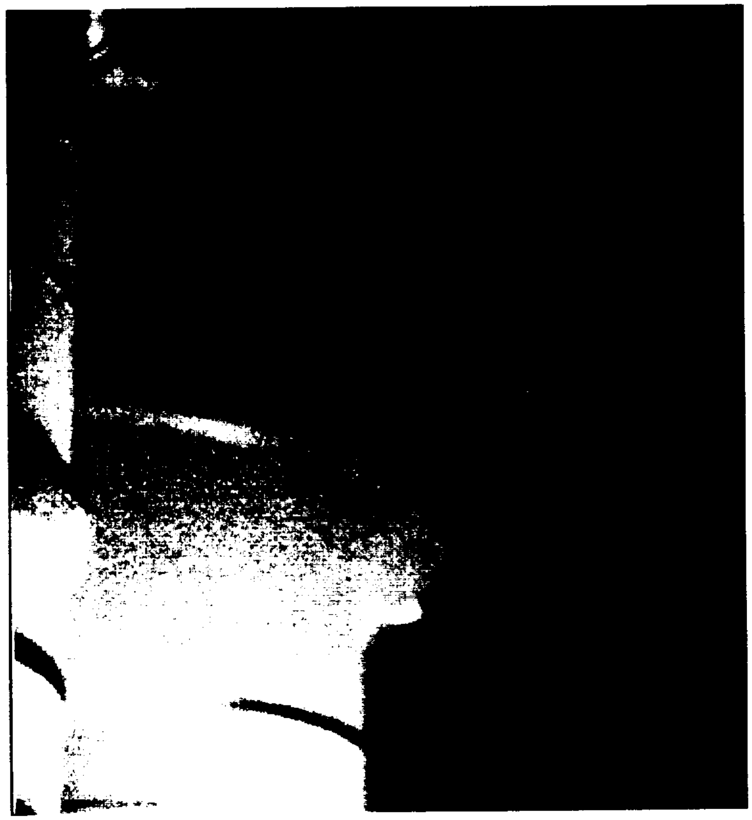


Figure 2.3 (D) White Vapor Trail near ET Aft Dome

A white vapor trail or streak was noted near the ET aft dome during liftoff at 02:48:15.7 UTC (E31, E52). This streak was probably caused by visible moisture.

The SSME Mach diamonds appeared to form in the expected sequence as seen on camera E19 and recorded in Table 2.3. No follow-up action was requested.

SSME	TIME (UTC)
SSME #3	02:48:11.884
SSME #2	02:48:11.914
SSME #1	02:48:11.922

Table 2.3 SSME Mach Diamond Formation

2.4 ASCENT EVENTS

Multiple white flashes, probably due to atmospheric effects, were seen aft of the vehicle near the SSME exhaust plume from 02:48:27 through 02:48:31 UTC (E52, E223, E224). A small white flash was seen between the SRBs and the bodyflap.

Body flap motion was visible during ascent from 02:48:42 through 02:49:07 UTC (E207). This motion did not appear to be as pronounced as that seen on STS-86. Measurements of the amplitude and frequency of the STS-89 body flap motion are not planned.

An orange-colored flare, probably debris induced, was seen in the SSME exhaust plume during ascent at approximately 02:48:34.939 UTC (E212, E223, E224).

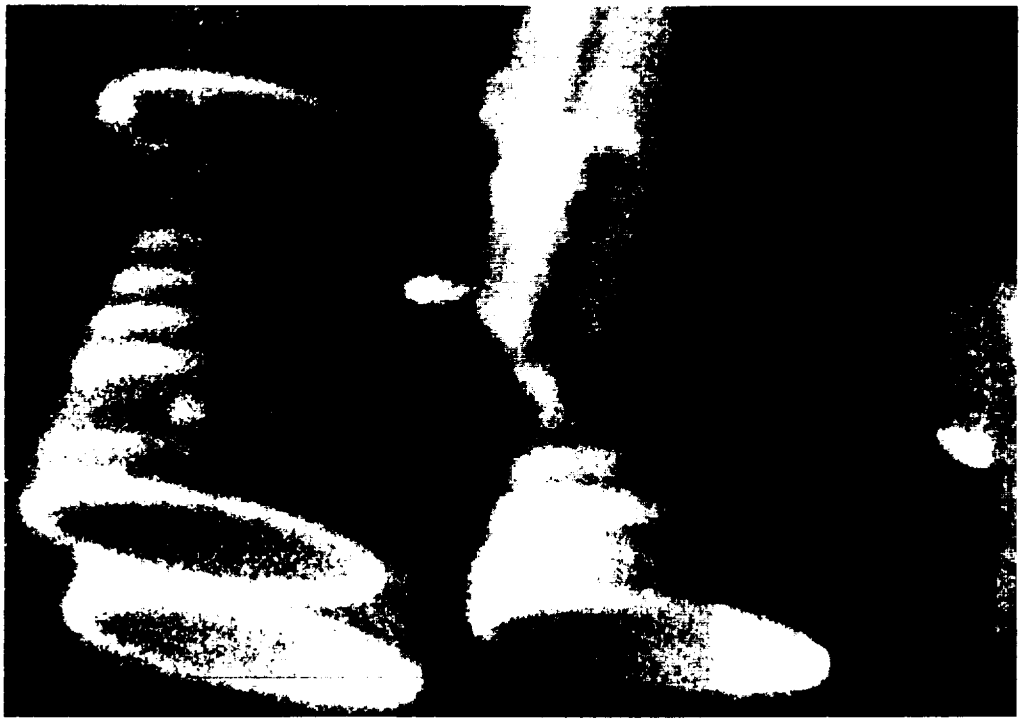


Figure 2.4 (A) Partially Detached DMHS Blanket

An object that appeared to be a partially detached DMHS (Dome Mounted Heat Shield) blanket was seen in the vicinity of the right OMS nozzle and the RCS stinger during ascent (E207).

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK

2.5.1 Analysis of the Umbilical Well Camera Films

Two rolls of 16mm umbilical well camera film from mission STS-89 were received: the 16mm film (5mm lens) and the 16mm film (10mm lens) from the LH2 umbilical. The 35mm film from the LO2 umbilical well camera was unusable due to darkness and was not printed. The +X translation maneuver was not performed on STS-89. Timing data was present on the 16mm films.

The LSRB separation appeared normal on the 16mm umbilical well camera films. Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing prior to SRB separation was seen. Numerous irregularly-shaped pieces of debris

(charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Normal blistering of the fire barrier material on the outboard side of the LH2 umbilical was seen. Ablation of the TPS on the aft dome was normal. The LSRB nose cap was visible during SRB separation. The presence of the RSRB nose cap could not be confirmed because of the dark view.

As in the case of the 35mm umbilical well camera film, the post-separation ET was not imaged on the 16mm films. The ET separation film sequences for both of the 16mm films were dark and unusable due to the nighttime conditions.

2.5.2 Analysis of the Handheld Photography of the ET

Thirty-seven images of the ET were acquired using the handheld 35mm Nikon camera with a 400mm lens (film roll #332). The exposure and focus of the photography is good. However on many of the images, a substantial portion of the ET was in shadow (detail not visible) because of the sun angle. Views of the sides, nose, and aft dome of the ET were acquired. No venting from the ET was observed. The averaged tumble rate was estimated to be approximately 12 degrees/second (see section 2.5.5). The normal SRB separation burn scars and aero-heating marks were noted on the ET TPS.

The ET was estimated to be about 4 to 5 km from the Orbiter on the first picture. This greater than normal distance between the Orbiter and the ET (because of the sun rise terminator) resulted in the minimum resolvable object size on the ET to be only 15 to 20 inches at best. The shadows and limited resolvable object size hindered the analysis of this photography. Timing data is present on the film. The first picture was taken at 31:11 (minutes:seconds) MET. The last picture was taken at 33:46 MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows (STS-89 was the second flight with the roll-to-heads-up maneuver).

2.5.2.1 ET Imagery Enhancements

In an attempt to improve the spatial detail on the handheld ET film, both photographic film enhancements and electronically digitized enhancements of the STS-89 external tank hand-held photography were made. Selected original full-frame views were scanned by JSC-BT4/Digital Image Laboratory at a resolution of 4096 pixels by 6144 pixels. Image processing software was used to further enhance the images using techniques that included enlarging, contrasting, and (on the digital images) edge sharpening. Enlarged prints of the enhancements were made on a Fujix Pictrography 3000 Photo Process Printer, at 400 dots per inch. Selected enlarged views were also printed from the original film in the JSC photographic laboratory using conventional processing for comparison to the digitized prints. The original film was also forwarded to the US Navy (JICPAC, Pearl Harbor) for enhancements using specialized equipment. These enhancements did not provide any additional information.

Damage to the external tank was not confirmed from the available enhancements. The only possible damage was seen on the +Y intertank thrust panel and on the +Y LH2 tank-to-intertank close-out flange (frames 9, 13, 24, and 28). The possible damage appears as small light-colored marks (possible divots) not much larger than the original film grain size. The light-colored mark on the intertank close-out flange between the +Y thrust panel and the LO2 feedline is approximately 9 inches in size (divots on this flange is a typical occurrence).

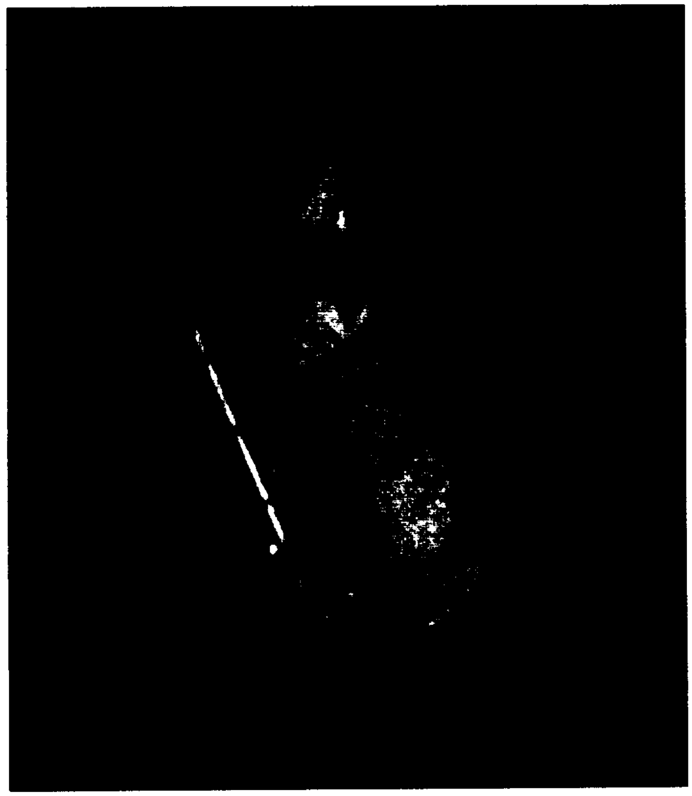


Figure 2.5.2.1 (A) Enhanced Image of Damage to the ET +Y Intertank Thrust Panel

Figure 2.5.2.1 (B) Enhanced Image of the ET -Y/-Z Intertank

The ET intertank TPS on the side away from the Orbiter (-Z axis) appears to be normal.

No damage was confirmed on the views of -Y ET Thrust panel.

2.5.2.2 Analysis of the Camcorder Video of the ET

Two minutes and fifty-seven seconds of post-separation downlink video of the ET were acquired by the astronauts. Similar to STS-87, numerous pieces of debris were visible throughout the video sequence. Some of the debris (probably ice) was out of focus suggesting a close proximity to the Orbiter window. The tumbling and rolling motion of the ET was visible on the video. Timing data was not present on the downlink video or on-board ET video.

2.5.2.3 ET Tumble Rate Analysis

Table 2.5 contains the STS-89 ET MET times, tumble cycles, and averaged tumble rate determined from the crew handheld film. The ET rate of tumble, i.e., the end-to-end rotation of the ET about its center of mass, was measured using the thirty-seven available frames on the Nikon 35mm format film (roll #332). The ET tumbled approximately seven cycles over the entire film sequence. The axis of rotation was roughly along the Z axis. No significant roll about the X axis was observed. No venting from the ET was observed. The average tumble rate was estimated to be approximately 12 degrees/second. The distance of the ET could not be measured because the full diameter of the ET was not visible due to the shadows. However, based on MET time and previous mission separation rates, the ET was estimated to be 4 to 5 kilometers from the Orbiter

when the photography was acquired. The STS-89 pictures were acquired later than usual; this delay may account for the higher than typical tumble rate measurement. Timing data was present on the handheld film. The video of the ET was not considered useable for tumble rate analysis.

STS-89 ET Tumble Rate From the HandHeld 35mm Nikon Camera					
Frame Number	**MET (mm:ss)**		**Tumble Cycle**	**Time per Cycle in Sec.**	**No. of Cycles (Tumble Rate)**
1	31	11	Start		
5	31	42	End	31	1 Cycle (12 deg/sec)
6	31	45	Start		
10	32	18	End	33	1 Cycle (11 deg/sec)
14	32	44	Start		
17	33	15	End	31	1 Cycle (12 deg/sec)
20	33	25	Start		
25	33	52	End	27	1 Cycle (13 deg/sec)
26	33	55	Start		
30	34	54	End	59	2 Cycles (12 deg/sec)
31	34	59	Start		
35	35	27	End	28	1 Cycle (13 deg/sec)
			Total	209	7 Full Cycles
Notes: 1) The total time for 7 cycles was 209 seconds.					
2) The average time for a 360 degree rotation was 29.9 seconds.					
3) The average tumble rate was 12 degrees/sec.					

Table 2.5.2.3 HandHeld Photography - ET Tumble Rate

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis

Film camera EL7 was used to determine the landing sink rate of the Orbiter main gear and camera film EL1 was used to determine the nose gear sink rate. The sink rates of the Orbiter were determined over a one-second time period prior to main and nose gear touchdown.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb vehicle and 6.0 ft/sec for a 240,000 lb vehicle (the landing weight of the STS-89 Orbiter was reported to be 216,635 lb). The sink rate measurements for STS-89 are given in Table 2.6.1. In Figure 2.6.1(A), and 2.6.1(B), the trend of the measured data points for the image data is illustrated.

Sink Rate Prior to Touchdown (1 Second)	
Main Gear	0.5 ft/sec.
Nose Gear	5.4 ft/sec.

Table 2.6.1 Sink Rate Measurements

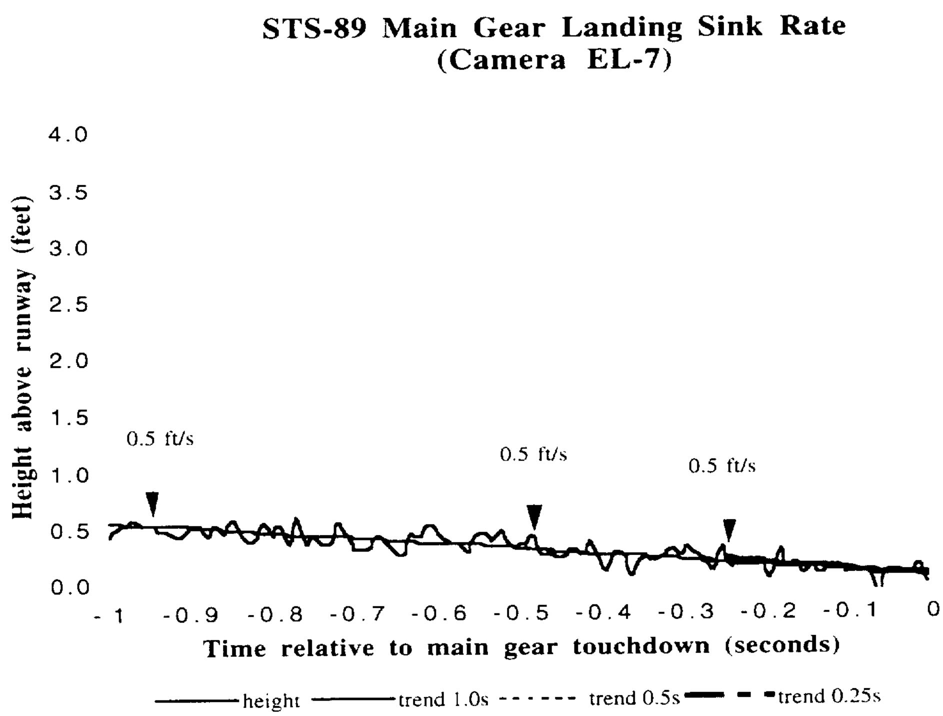


Figure 2.6.1 (A) Main Gear Height versus Time Prior to Touchdown

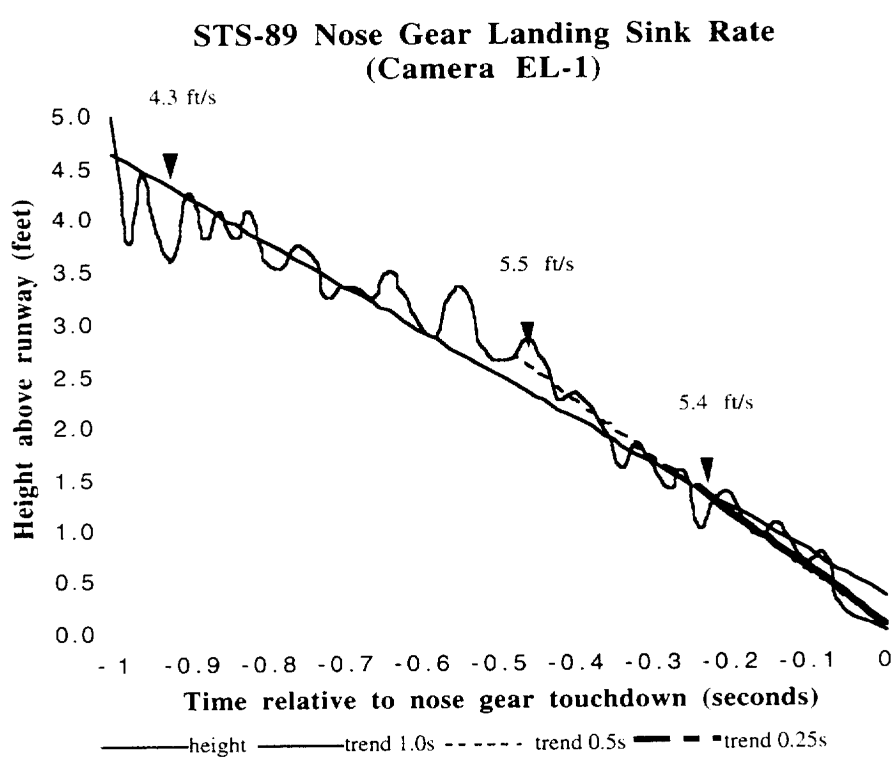


Figure 2.6.1 (B) Nose Gear Height versus Time Prior to Touchdown

2.7 OTHER

2.7.1 Normal Events

Normal events observed include: ice debris and vapor from the ET/Orbiter umbilical areas during SSME ignition; RCS paper debris prior to liftoff; ET twang; multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals at disconnect; debris in the exhaust cloud after liftoff; vapor from the SRB stiffener rings after liftoff; ET aft dome outgassing and charring of the ET aft dome; linear optical effects; expansion waves; contrails from the Orbiter wing tips; SRB plume brightening prior to SRB separation; slag debris during and after SRB separation.

2.7.2 Normal Pad Events

Normal Pad events observed include: hydrogen ignitor operation; MLP deluge water activation; FSS deluge water operation; GH2 vent arm retraction; TSM door closure; sound suppression system water operation.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of: EP73 (98-01) February 23, 1998

TO: Distribution

FROM: EP73/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-89

The launch of Space Shuttle mission STS-89, the 12th flight of the Orbiter Endeavour occurred on January 22, 1998, at approximately 8:48 p.m., Central Standard Time from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Launch time was reported as 98:023:02:48:15.017 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

All requested engineering films and videos were received and reviewed at MSFC. These films and videos are dark due to the night sky. This greatly reduces the amount of data recorded. Only the aft-end of the vehicle is visible in the tracking films.

The Orbiter umbilical-well cameras that record the SRB and ET separation events only provided data during the SRB separation event due to insufficient lighting at ET separation. The astronauts recorded images of the ET after separation with an 8mm camcorder and hand-held 35mm Nikon camera. The image sizes of the ET from these cameras was small and provided little detail.

No anomalies were noted. Three streaks in the SSME#1 plume were observed at 02:48:13.836 UTC, 02:48:16.155 UTC and 02:48:16.889 UTC. These streaks are engine produced and were observed from several cameras. Debris-induced SSME streaks were also observed on this mission.

The images taken of the ET after separation by the astronauts provided little detail of the ET thrust panels TPS condition. On the previous mission, STS-87, TPS damage was visible on these panels. Due to the small image size, little detail and low contrast in this area of the imagery, it is inconclusive that TPS damage was sustained on the ET thrust panels.

The following event times were acquired from photography:

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	02:48:15.025	Camera E9
M-2 PIC Firing	image too dark	Camera E8
M-5 PIC Firing	02:48:15.025	Camera E12
M-6 PIC Firing	02:48:15.025	Camera E13
SRB Separation	02:50:18.36	Camera E207

This report and additional information are available on the World Wide Web at URL:

http://photo4.msfc.nasa.gov/STS/sts89/sts89.html.

For further information concerning this report, call Tom Rieckhoff at (205)544-7677 or Jeff Hixson, Boeing North American at (205)971-3082.

Tom Rieckhoff

Thomas J. Rieckhoff
Propulsion Systems Analysis Branch

Distribution:
CR01/Ms. Harris
SA01/Mr. McCool
SA21/Mr. Hopson
SA31/Mr. Counts
SA41/Mr. Kennedy
SA51/Mr. Henson
SA71/Ms. Martin
EA01/Mr. Taylor
ED01/Dr. Humphries
ED21/Mr. Bianca
EE11/Mr. Rudolphi
EE12/Mr. Pung
EE21/Mr. Worlund
EE31/Mr. Harsh
EE31/Mr. Moye
EE31/Mr. Pessin
EE51/Mr. Nichols
EP01/Dr. McConnaughey

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1998	20-31 January 1998 (Final)

4. TITLE AND SUBTITLE

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-89

5. FUNDING NUMBERS

OMRSOOUO

6. AUTHOR(S)

Gregory N. Katnik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

John F. Kennedy Space Center, NASA
Process Engineering/ Mechanical Systems Division
ET/SRB Branch, Mail Code: PK-H7
Kennedy Space Center, Florida 32899

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Blanket Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-89. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the ice/debris/thermal protection systems conditions and integrated photographic analysis of Space Shuttle mission STS-89 and the resulting effect on the Space Shuttle Program.

14. SUBJECT TERMS

SUBJECT CATEGORY: 15, 16
STS-89 Thermal Protection System (TPS)
Ice Debris Photographic Analysis

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

KSC DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS REPORT DISTRIBUTION LIST 1/98

NASA - KSC

AA-C/L. J. Shriver
MK/D. McMonagle
MK-SIO/R. W. Page
PK-D2/R. Harrison
PK-H/C. Stevenson
PK-H7/G. Katnik (7)
RO-PAD/A. Willett
PZ-C2/C. Brown

SK/F. Kienitz
USK-321/R. S. Herman
USK-437/M. Valdivia
ZK-86/F. J. Foster
BICO-RVITS/R. B. Hoover
MMC-15/D. S. Otto
USBI-LSS/L. Clark

NASA - HQ

QSO/W. Comer

NASA - JSC

Johnson Space Center
Houston, Texas 77058

EP2/P. Cota
ES3/J. Kowal
MV3/D. Camp
SN3/E. Christiansen
SN5/M. Gaunce

NASA - MSFC

Marshall Space Flight Center
Huntsville, AL 35812

ED31/D. Andrews
EE31/M. A. Pessin
EE31/M. G. Harsh
EP42/T. J. Rieckhoff

Rockwell - Downey

Rockwell International
12214 Lakewood Blvd
Downey, CA 90241

AE21/J. McClymonds
FA44/R. Ramon

Martin Marietta

P. O. Box 29304
New Orleans, Louisiana 70189

Dept. 3571/S. Copsey
MAF Technical Library